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A NEW ANALCITE ROCK FROM LAKE SUPERIOR

Among other regions on the northern shores of Lake Superior examined last summer by the writer for the Ontario Bureau of Mines the vicinity of Heron Bay, where the Canadian Pacific Railway first touches the lake when coming from the east, proved very interesting, a thick series of schist conglomerates with pebbles and bowlders mainly of felsite and quartz-porphyry occurring there, mapped by Dr. Bell of the Canadian Geological Survey as Huronian. Along the rocky shore of the bay, and also in cuttings on the railway west of the station, good exposures of these rocks are seen, sometimes so rolled out that the forms of the pebbles are almost, or completely, lost. Crossing the schist conglomerates are numerous dikes, which unfortunately were not carefully studied owing to lack of time, though hand specimens of the more typical dike rocks were taken. In the field the dikes were considered to consist of diabase, diabase-porphyrite, and felsite, all common rocks in the western Keewatin.

Microscopical study of the specimens obtained showed that the diabase and porphyrite present no unusual features, and that one of the felsitic-looking rocks is quartzless porphyry of a kind common in western Ontario. Another rock taken for felsite, dark red and slightly spotted with green, turns out, however, to

be of a new type, and will be described here because of its interesting mineralogical and chemical composition.

The specimens were obtained near mile 804 in a cutting on the railway, one being chosen to represent the freshest material seen, another weathered, and presenting a mottling of red and dark green, almost suggesting a variety of amygdaloid. Sections of the latter specimen are so completely weathered that little of its original composition can be determined; but sections of the fresh specimen show that the greenish spots consist almost wholly of feldspars having a confused radiating arrangement giving spherical forms; while the red part is composed of an isotropic base like a clear glass penetrated by radiating bundles of green prisms and also larger bundles of feldspar laths, brown with particles of iron oxide. A little calcite scattered through the section proves that the rock is no longer fresh.

The vague spheres of feldspar often have an imperfect black cross in polarized light, and consist mainly of orthoclase, somewhat turbid and specked with brown iron oxide, with a little of the green mineral intermixed. The rest of the rock contains some orthoclase also, but consists chiefly of the isotropic substance inclosing the radiating bundles of prisms referred to before. The green prisms are fresh in color and appearance, and are usually distinctly dichroic, dark green when the prism is parallel to the chief section of the nicol, yellowish-green at right angles to this position. Extinction is nearly parallel, but angles of $4\frac{1}{2}^\circ$ occur. The larger crystals sometimes have sharpened ends. The mineral was at first taken for hornblende, but is no doubt aegyrite.

The other mineral forming radiating bundles is probably plagioclase, clearer parts showing twin lamellae, whose angle of extinction, however, could not be sharply determined owing to the small size of the lamellae. Many of these plagioclase strips are reddish-brown and almost opaque, with particles of brown iron ore.

The only other primary mineral observed, except a few needles of apatite, is the isotropic base in which the crystals

just referred to are embedded. It is clear and transparent, with some dusty spots, however, and has not the look of ordinary volcanic glass. With high powers a delicate, but distinct, system of cubic cleavage lines can be seen, proving that the mineral is isometric and therefore probably analcite, though no crystal forms were observed.

An attempt was made to isolate the glassy mineral with a heavy solution, analcite being lighter than any other rock forming mineral belonging to eruptives, and it was found that 17 per cent. of the powder floated when gypsum was used as an index (spec. grav. 2.32); but when examined with the microscope the powder was found to contain doubly refracting portions embedded in the isotropic ones, and some isotropic portions were noticed associated with the heavier minerals. Some of the rock was then treated with strong hydrochloric acid, when partial gelatinization took place, and it seemed wise to reduce the whole to dryness to render the silica insoluble. It was found that 27.76 per cent. of the whole weight went into solution, omitting, of course, the silica of the mineral which gelatinized when treated with acid. A second portion treated in the same way as a check gave 30.35 per cent. of soluble matter. Probably the first portion taken contained more of the sphaerulitic parts than the second. An analysis of the soluble part made by myself gave the following results:

Al_2O_3	10.90
Fe_2O_3	3.13
CaO	1.03
MgO	trace
Na_2O	6.60
K_2O	not det.
H_2O (at 100°)	.69
H_2O (at red heat)	4.85
CO_2	.93
	28.13

We may assume that the only minerals in the rock which would be appreciably dissolved by HCl are analcite, limonite,

and calcite. If we subtract the lime and carbonic acid, as forming calcite, and the ferric oxide with a proportionate amount of water (.45 per cent.), as forming limonite, we have left the following:

Al_2O_3 - - - - -	10.90	.107 = 1
Na_2O - - - - -	6.60	.106 = 1
H_2O (at red heat) - -	4.40	.244 = 2.28

Reducing to molecular ratios, alumina and soda are equal, and water stands at 2¼, proportions that correspond to those of analcite, except for a little too much water.

If the alumina in analcite equals 10.90 per cent. the corresponding amount of silica, four molecules, is 25.49 per cent., and the whole percentage of analcite in the rock is almost exactly 47, nearly one half. In the second part treated with acid, when 30.35 per cent. proved soluble, the amount of analcite must be more than half the whole weight of rock taken If we subtract the percentages of substances found in the first portion of rock dissolved in hydrochloric acid from the results of the complete analysis, and also the proper amount of silica to form analcite with the alumina, soda, and combined water, we shall have left the materials forming the insoluble ingredients of the rock.

The complete analysis given below was made by Mr. H. W. Charlton, his results being put in column I. In column II an analysis by Dr. Mann of cancrinite-aegyrite-syenite from Siksjö-Berg in Dalarne[1] is given because of its rather close resemblance to No. 1; and in column III an analysis of analcite-basalt from the Basin, Colorado, by W. F. Hillebrand.[2]

A little more than 46 per cent. of the rock remains unaccounted for by the partial analysis; and if we suppose the whole of the potash to belong to orthoclase and the unused portion of iron oxide (1.40 per cent.) to belong to aegyrite, we have left

[1] Neues Jahrbuch für Mineralogie, 1884, II, p. 193; as quoted by ZIRKEL, Lehrbuch der Petrographie, Band II, p. 410.

[2] WHITMAN CROSS, an Analcite-Basalt from Colorado, JOUR. GEOL., Vol. V, No. 7, 1897, p. 689.

	I	II	III
SiO_2	52.73	51.04	45.59
TiO_2		.29	1.32
ZrO_2			.03
Al_2O_3	20.05	20.47	12.98
Fe_2O_3	3.43	1.89	4.97
FeO	.99	2.19	4.70
MnO			.14
CaO	3.35	2.62	11.09
SrO			.12
BaO	.11		.13
MgO	.17	.97	8.36
K_2O	4.77	3.52	1.04
Na_2O	7.94	11.62	4.53
H_2O (at 100°)	.69	5.85	.51
H_2O (at red heat)	4.85		3.40
P_2O_5	trace	.27	.91
Cl			.05
CO_2	.93	.62	
	100.01	101.35	99.87
Spec. Grav.	2.466	2.46	

silica, alumina, lime, and soda nearly in the proportions required for labradorite (Ab. 2 : An. 3), though the lime and soda are about one third in excess of the amount required, the excess being less than 1 per cent., however.

Summing up the results arrived at, the minerals forming the rock have the following percentages :

Analcite	47.00
Orthoclase	28.24
Labradorite	13.00
Aegyrite	4.04
Limonite	3.59
Calcite	1.96
	97.83

In this computation moisture removed at 100°, unimportant percentages of magnesium and barium oxides, etc., amounting in all to 1.47 per cent., have been neglected.

The composition of the rock as shown by the analysis differs widely from that of analcite-basalt, as may be seen from a com-

parison of columns I and III, the latter being more basic, containing less alumina and alkalies, and far more lime and magnesia. It corresponds fairly well, however, to the composition of nepheline syenite, the only important difference being in the amount of water. The syenite from Dalarne, whose analysis is given in column II of the table, having its nepheline weathered to a hydrous mineral, resembles this rock closely in composition, the only important difference being the larger percentage of soda. In their unusually low specific gravity, 2.46, also the two rocks are alike.

One naturally expects to find the dike containing the rock above described in connection with some boss of nepheline syenite; but the slight examination hitherto made of the region by Dr. Bell and myself has not disclosed any area of that rock.

If the analcite rock of Heron Bay had a granular texture, it would appropriately be named analcite-syenite, after the analogy of nepheline-syenite; but its peculiar structure of spherical groups of orthoclase embedded in a ground of analcite containing radiating bundles of plagioclase laths and aegyrite needles sets it quite apart from the syenites. It will probably be wise to give it a separate name, and Heronite, from the name of the locality where it occurs, is suggested as suitable.

Heronite may be defined as a dike rock consisting essentially of analcite, orthoclase, plagioclase, and aegyrite, the analcite having the character of a base in which the other minerals form radiating groups of crystals. The analcite clearly represents the magma left after the crystallization of the embedded minerals; and it is evident that it can be formed only from a magma highly charged with water, and therefore under pressure. It is equally evident that Heronite, like other analcite rocks, cannot be an effusive, since under those circumstances the water would escape;[1] and that its nearest relatives among effusive as well as plutonic rocks are to be found in the group containing nepheline.

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[1] Cf. PIRSSON, Analcite Group of Igneous Rocks, JOUR. GEOL., Vol. IV, No. 6, pp. 686–688.

CORUNDIFEROUS NEPHELINE-SYENITE FROM EASTERN ONTARIO

A CONSIDERABLE area of nepheline-syenite was discovered about six years ago in Dungannon township, Hastings county, Ontario, by Dr. F. Adams, who described the rock briefly in his "Report on the Geology of a portion of Central Ontario," and more fully in the *American Journal of Science*.[1] In 1896 corundum was found in the same region by Mr. W. F. Ferrier, and in the following year Professor W. G. Miller was instructed by Mr. Archibald Blue, director of mines of Ontario, to examine and report upon the corundum-bearing rocks. In the course of his work it was found that the corundum occurred not only in ordinary syenites but also in nepheline-syenite.[2] In November 1898 the present writer examined an outcrop of the latter rock for the Bureau of Mines on York branch of Madawaska River at the northeast corner of Dungannon township or just within Carlow, several miles from Dr. Adams' localities, and presenting a number of new and interesting features.

The rock forms a ridge running nearly north and south for about 350 yards with a width of about 20 yards, and having a well defined schistose character, so that at first sight it would be called gneiss. It is light to dark gray in color, the darker layers containing much biotite, the lighter ones more nepheline and plagioclase. On much of the weathered surface numbers of small crystals of corundum stand out, having resisted weathering better than the other constituents. In hand specimens of the unweathered rock, however, the corundum is scarcely noticed, and the rock has quite the appearance of fresh gray gneiss, the nepheline looking like quartz.

[1] Geol. Surv. Can., 1892–3, Part J, p. 5; Am. Jour. Sci., Vol. XLVIII, July 1894, pp. 10–18.

[2] Bur. Mines, Ont., Vol. VII, pp. 210–212.

Near the southern end of the ridge an irregular dike a few feet wide crosses the gneissoid rock, reminding one of pegmatite. It is white and consists of immense individuals of nepheline and muscovite, often several inches or even a foot long, with small patches of blue sodalite. No feldspar was seen in the dike, unlike examples described by Adams,[1] and no corundum was found in it.

As usual in nepheline-syenites there is great variation from point to point in the rock, easily seen on weathered surfaces and still more marked in thin sections. Adams finds, as essential ingredients of the outcrops near Bancroft, nepheline, plagioclase, and biotite or hornblende in small amounts; but scapolite and calcite usually occur, as well as various minor accessory minerals. Thin sections from the locality here described show more variety in constitution. All the minerals mentioned, except hornblende, occur, and the feldspars include orthoclase and also a little microcline as well as microperthite. The soda-lime feldspars are generally present in much larger amounts than the potash feldspars, and seem to have a wide range in composition as determined by optical means. A few have angles of extinction of 4° or 5° from the twin plane and appear to be albite as in the rock examined by Adams, others having a very small angle are probably oligoclase, while a considerable number range from 17° to 23° indicating labradorite. Some have broad and sharply cut twin lamellae, others very narrow and obscure ones. All the feldspars are beautifully clear and fresh as a rule, much more so than those of the associated Laurentian gneisses and granites.

The nepheline also is generally very fresh and, as mentioned by Adams, has not the color nor oily luster of eleolite, though it seldom shows crystal forms. Large individuals often contain inclusions, minute crystals of hornblende, of biotite, and long rows of tiny dots of a transparent doubly refracting mineral. Calcite inclusions sometimes occur completely enclosed in fresh looking nepheline. In one example the somewhat weathered nepheline contains crowds of slender transparent fibers or

[1] *Ibid.*, p. 11.

somewhat bent cords, having a little the look of apatite but with a small angle of extinction, perhaps tremolite. Occasionally decomposition products occur along fissures, having the appearance of kaolin but without any distinct structure.

Scapolite is found in about a third of the sections, sometimes almost to the exclusion of other colorless ingredients and has the look of a primary mineral. Its anhedra meet the adjoining feldspar or nepheline in a sharply defined way with no hint of weathering in the latter minerals. Muscovite is a very common constitutent of these rocks, being found in more than half of the thin sections examined, generally as large primary looking individuals, sometimes associated with biotite though often without it. Biotite is practically the only dark mineral in the rock, hornblende not having been observed. As in the specimens examined by Adams, it is very dark in color and has a very small axial angle. Augite was found as small blue-green anhedra in one section only. Magnetite was not found, and apatite was rare.

The most interesting accessory mineral is corundum, which sometimes occurs in fairly well formed barrel-shaped crystals half an inch in length, but is usually smaller and often forms only minute rounded grains. Its color is gray or less often pale bluish. Owing to the hardness of corundum it was found difficult to prepare sections rich in crystals and only two have been studied. Under the microscope their high refractive index and greater thickness than the rest of the section cause the corundum grains to stand out sharply. They are apt to be arranged in clusters in association with muscovite, often completely enclosed in it.

Although the rock here described has a well marked schistose structure, there is nothing in its microscopic characters to suggest shearing or crushing, no mortar structure nor granulation, and seldom even undulatory extinction to hint at a state of strain. The rock as a whole is hypidiomorphic granular, and except corundum none of its constituents show much tendency to crystalline form.

The coarse-grained dike with its individuals of nepheline half a foot wide is not easy to study in thin sections. The nepheline proves under the microscope to have been slightly fractured, very narrow fissures being filled with a rather brightly polarizing mineral, perhaps feldspar. The few inclusions are much like those of the nepheline in the schistose rock, but in one section rather large portions of muscovite are enclosed. The large crystals of pale lavender muscovite have no unusual characters except their often perfect idiomorphy as against nepheline and sodalite. The crystals are not hexagonal in cross section but four sided having one angle of about 60°. The basal cleavage is somewhat inclined to the prismatic edges, though a series of pyramids having a very long C axis makes it difficult to determine the angle. In thin sections cut across the cleavage this muscovite has an extinction angle of 3° to 5°.

If single thin sections were to be diagnosed alone four quite distinct types of rock could be described from this outcrop; a nepheline-muscovite rock; a rock made up chiefly of scapolite and muscovite with a little biotite, plagioclase, and nepheline; a rock containing about equal parts of plagioclase and nepheline with some mica; and a rock consisting of orthoclase, microcline and nepheline with some mica. There are, however, transitions between these varieties, and it would be unwise to split up what is so evidently a geological unit into rocks of different names when the whole is so well defined in general character, though each hand specimen shows differences from its neighbors.

No analysis has been made of this rock, but one specimen yielded nearly 10 per cent. of corundum in a heavy solution. As there was no magnetite nor other heavy mineral present the separation was very complete, corundum having a much higher specific gravity than the other ingredients. Since every mineral present, except the trifling quantity of calcite and apatite, contains alumina, nepheline in particular to the extent of more than 30 per cent., this oxide must occur in very large amounts. On the other hand iron oxides must be very low, since the only iron-bearing constituent is biotite.

A specimen of nepheline-syenite was obtained from Lancaster's farm, some miles west of the locality just described, from a small outcrop showing no schistose structure. It is coarser grained, but of the same color and general appearance as the rock from York branch. Thin sections show, however, that it has been subjected to shearing forces, since there is a granulation round the larger pieces of feldspar and nepheline suggesting mortar structure. Nepheline is present in large amounts and also a peculiar type of microperthite having long fibrous looking inclusions of one feldspar in another. the main mass being in parts very finely striated (anorthoclase?) with twin lines making an angle of about 23° with the most marked cleavage. Oligoclase and biotite occur in smaller amounts, the latter as usual very opaque. Some of its outer scales weather to a bronze-brown color, are dichroic, and have the optical axes much farther apart than in the fresh mica.

Specimens of a medium-grained white rock dotted with darker minerals come from a locality not visited by the writer, in Methuen township, Peterboro county, and are interesting as containing many dark brown corundum crystals having a bright bronze luster on basal partings, as well as minute crystals of magnetite.

Thin sections of one specimen disclose chiefly plagioclase, finely striated and with a low angle of extinction from the twin plane; a little microcline, nepheline and muscovite making up the rest of the rock. Sections of another specimen very similar in appearance contain more muscovite and a large amount of nepheline, or rather of a turbid decomposition product, confusedly scaly or fibrous, having high double refraction. The mineral seems to have parallel extinction, fuses readily without intumescence to a white glass, and gives water in the closed tube, so that it is no doubt a uniaxial or rhombic zeolite, perhaps natrolite. The corundum is very opaque so that only minute particles of crushed crystals can be studied satisfactorily. It contains many inclusions of two kinds, slender black needles lying parallel to one another, and brownish-red strips and plates

somewhat irregularly shaped and placed. The latter are probably hematite and produce the bronze luster seen on basal planes of the corundum. Extinction is parallel to the needle-like inclusions, and there is a rather strong dichroism, violet when the needles are parallel to the chief section of the lower nicol and reddish-brown in the opposite position. Some fragments, no doubt parallel to the basal plane, are not dichroic.

The first of the two specimens might be named a plagioclasite (anorthosite contains a more basic feldspar) if taken separately, but the second does not differ from typical examples of the York branch nepheline-syenite except in the complete weathering of its nepheline, and probably both are varying forms of the same rock mass.

Through the kindness of the director of the Bureau of Mines specimens of corundum rocks from Raglan township in Renfrew county, about twenty miles northeast of Dungannon, have been placed at my disposal. One is white, somewhat schistose, and much like the Methuen specimens except that it contains biotite, and that the pale greenish corundum crystals are almost an inch in diameter and have no bronze shimmer on basal planes. Under the microscope it is found to consist mainly of plagioclase (oligoclase) and biotite, the latter pale greenish-brown, faintly dichroic and with a small axial angle. There are also a few large patches of colorless muscovite having a large axial angle. The specimen has the mineralogical composition of a diorite, though of a very unusual character; but Professor Miller states that nepheline-syenite occurs close by, apparently part of the same rock mass, though not so highly corundiferous.[1]

These white rocks were taken for limestone by farmers of the region, and an attempt was made to burn them for lime, of course, in vain. Hand specimens, partly fused, were taken from the kiln and supposed to be nepheline-syenite, many of them doubtless having that composition; but the one provided for microscopic examination contains no nepheline. It is evidently part of a bowlder and is schistose and pale gray to white on the

[1] Bur. Mines, Ont., 1897, p. 222.

surface, but mottled bright blue and white where broken. Under the microscope the rock is found to consist of scapolite, sodalite and biotite with a very little orthoclase. The scapolite forms the greater part of the rock, the spaces between its anhedra being filled with sodalite; the latter blue throughout when in small portions, but only on the edges when in large ones, the center being colorless and isotropic. The bowlders are said by Miller to be blue only after being burnt in the lime-kiln.

The biotite is deep red-brown in color, has a high absorption and a wide axial angle, perhaps the result of heating; just as many dark biotites turn brown by weathering and have a wider angle between the optical axes.

There are small quantities of an unknown mineral present, white, transparent and having a low double refraction, so as to give only dull blue or purple tints between crossed nicols. Two or three sections of it show an axial image consisting of a black cross opening out about as far as in many biotites, but without colored rings. It is optically positive.

About eleven years ago the writer collected a considerable number of specimens of nepheline-syenite from drift bowlders in the neighborhood of Cobourg, Ontario, which lies about south-southwest of the localities referred to above and from fifty to a hundred miles distant from them. At that time nepheline-syenite had not yet been reported from the province.[1] In a general way these specimens correspond in appearance and composition to those that have been described, though a number of additional minerals occur in them, the more important being hornblende, augite and garnet, both of the ordinary kind and melanite, the brown variety. Only one of the specimens collected then contains corundum; and it, though closely like the others in appearance, shows little or no nepheline and resembles in mineralogical constitution, one of the specimens from Methuen. The purplish-gray corundum crystals are quite large, and thin sections show the same needlelike inclusions

[1] Trans. Roy. Soc. Can., 1890, pp. 14–18.

and dichroism as the Methuen crystals, but not the hematite plates.

As there is not much doubt that the Cobourg drift bowlders originated in the nepheline-syenite region to the northeast, they have been referred to here and may be considered in connection with the rocks previously described.

In spite of the great variations in mineralogical composition to be seen in hand specimens all the rocks referred to have much in common; they are white to gray in color, generally schistose, often corundiferous, and present the same general habit, so that in field work they are naturally thrown together as nepheline-syenite and can be sharply distinguished from adjoining Laurentian gneisses, granites, and syenites. While not all of them contain corundum in large amounts they serve as a general guide to the discovery of the corundiferous rocks and are so used by prospectors for that mineral. Some of the ordinary syenites of the region, however, contain corundum also, and the largest crystals found occur in them.

Just why the magma which has solidified into the group of rocks described above should be so versatile in regard to mineralogical composition is not easily explained; but no other rock known to the writer shows so great a variety of types within short distances as may be found in the nepheline-syenites. It may be that experiments such as those of Morozewicz[1] will give the clue to this variability, which seems to depend on the large proportion of alumina in the original magma. The corundiferous varieties of nepheline-syenite represent magmas supersaturated with alumina but not saturated with silica.

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[1]See Review by T. A. JAGGAR: JOUR. GEOL., 1899, Vol. VII, No. 3, pp. 300, etc.

THE EFFECT OF SEA BARRIERS UPON ULTIMATE DRAINAGE

The causes which determine the location of river courses in the neighborhood of their discharge into the sea, where the currents are slow and their power of erosion small, are often quite insignificant.

If, however, a stream once becomes established in any given course, and the region through which it flows becomes elevated, its sluggish current at once becomes active and forms a valley of greater or less depth. Its tendency through subsequent changes in the land level is to remain in the valley approximately as originally formed. This tendency is especially strong if this original valley is parallel with the strike of the strata.

It is not the purpose of the present paper to discuss the development of intricate drainage systems along structural lines, and through long periods of time, but simply to suggest that a drainage system may sometimes have a portion of its course fixed, by spits and barrier beaches along the coast line, at the same time that the sediments which are to form the rocks of its future drainage area are being deposited; and also that the drainage when established thus early may remain more or less fixed through its subsequent history.

Along coast lines generally, and especially along those of gently sloping coastal plains, spits, bars, and barriers are more or less common. For our present purposes these may all be spoken of as barriers, and so far as the present paper is concerned it does not matter whether they are composed of sand, gravel, or coral; neither do the forces by which they are built up need to be discussed.

The lagoons between the barriers and the shore vary in length with the barriers, from a few hundred yards to many miles. Such lagoons are parallel to the shore and usually

almost at right angles to the course of the drainage entering them.

The drainage from the land must pass through these lagoons, often for almost their entire length before it can reach the sea through gaps in the barriers or around their ends. Thus it happens that long, low barriers, often of soft sand, and of insignificant height, which if inland would be slight obstacles to erosion, often control large drainage areas (Fig. 1).

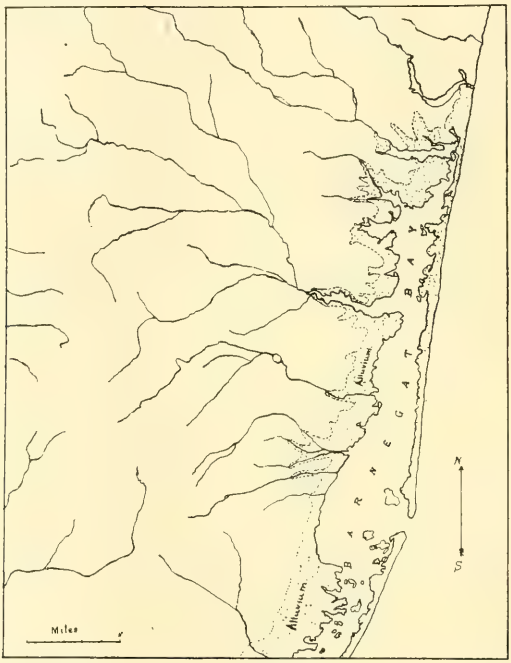

FIG. 1.—Barnegat Bay on the coast of New Jersey. The drainage, at present deflected by the barrier, passes through the bay and into the ocean.

Excellent examples of drainage controlled by barriers are to be found developed to a greater or less extent along the coasts of almost all countries. Along our own coasts the most marked examples are the streams flowing from Texas into the Gulf of Mexico; Indian River along the east coast of Florida; and the

streams emptying into Albemarle, Pamlico, and neighboring sounds. The drainage in all these localities is deflected many miles. Many less marked instances of deflected streams may be seen upon almost any map of a long coast line.

The writer's attention has been called by Dr. J. C. Branner to the stone reefs along the coast of Brazil. These reefs bear

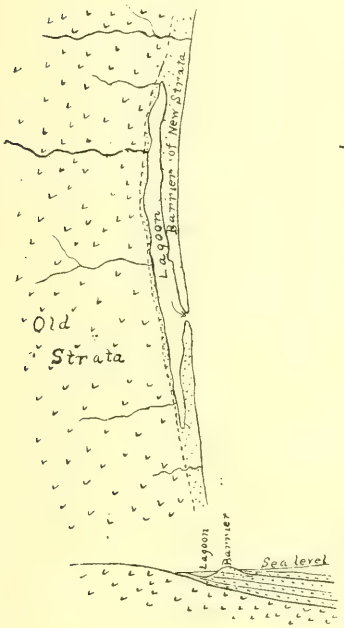

FIG. 2

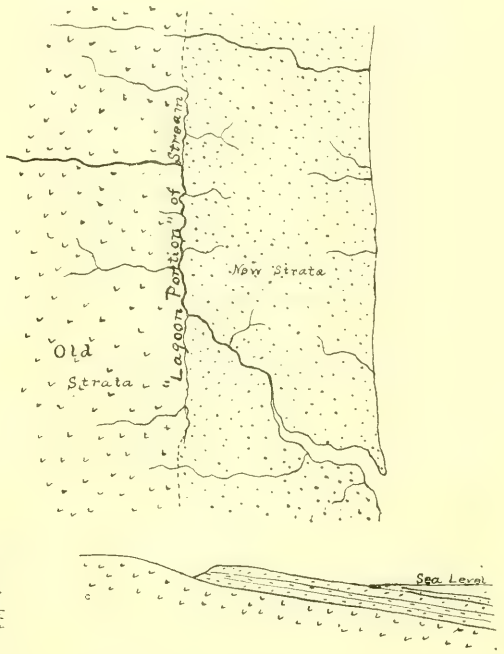

FIG. 3

FIG. 2 shows a shore line whose drainage is deflected by a barrier. The cross-section shows the relations existing between the barrier, lagoon, new, and older strata.

FIG. 3 shows the arrangement of drainage, as represented in Fig. 2, after the elevation of the land. The "lagoon portion" of the stream is here shown as being directly along the contact between the newer and older groups of strata.

the same relation to the shore as ordinary sand barriers, and they are probably old barriers whose sands early became cemented. In such cases of early solidification, the "lagoon" portion of the resulting land stream is, of course, held in position much more firmly than in the case of loose sands.

Shore deposits usually have a slight seaward dip. It happens, therefore, that the streams entering lagoons behind barriers may not only have their courses determined early in their history, and that subsequent erosion after the land becomes elevated tends to deepen the channel in the position determined, but also that this position is parallel with the strike of the strata. The subsequent tendency of the stream, therefore, is to remain in this original course established for it by the lagoon, as shown in Figs. 2 and 3.

If the coast, along which such stream deflection occurs, happens to be rising, or if the barriers are being added to from the seaward side, the barriers, at first narrow and low, may become gradually wider and higher and finally form a considerable land area. In this new area a new drainage system will develop, a portion of it being drained landward to its old lagoon, the rest draining either directly or through a new lagoon, into the ocean, as shown in Figs. 3 and 4.

If the land level remains unchanged, the lagoon is left inland and controls the drainage of the region on its landward side with little or no tendency toward erosion. If, however, the land becomes slowly elevated, the old "lagoon portion" becomes an active stream and cuts out a channel in and along the strike of the new rocks. As the shore becomes more and more elevated, and the stream is left further inland, this portion of the channel becomes more firmly established in its course. Thus it becomes an inland stream, which had a greater or less portion of its length originally established parallel with the coast, with the contact between groups of strata and also with the strike of the rocks, and not across the strike or outcrop, as is so commonly taken for granted for the original courses of streams. (Fig. 3.)

It is obvious from what has been said that the "lagoon portions" of streams will be determined in a direction approximately parallel with the general direction of the contacts of the newly-formed geologic groups; they may be directly along this line, or they may be several miles on either side of it.

Fig. 1 may be taken as a type to illustrate this. Here the

barrier of "alluvium" enclosing Barnegat Bay on the coast of New Jersey is from three to five miles from the contact between the "alluvium" and the older beds of gravel, sands, and clays. If Barnegat Bay were silted up by sediments from the landward

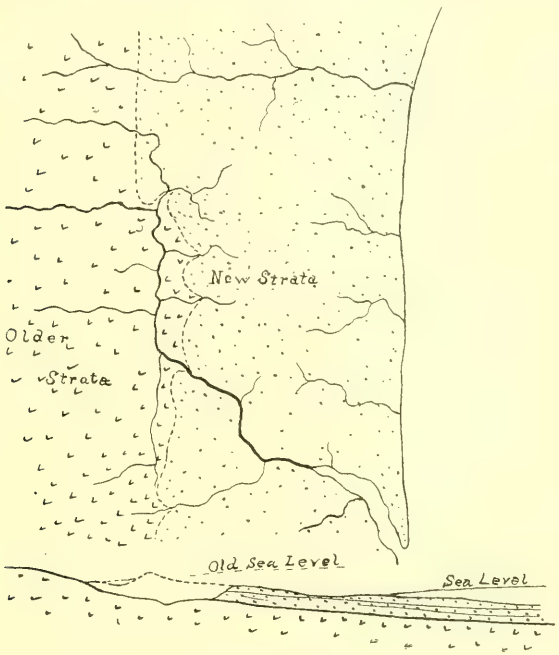

FIG. 4.

FIG. 4 is a further development of Fig. 3; the "lagoon portion" of the old stream having for the most part settled itself down in the underlying strata. The contact between the newer strata and the older being shifted seaward by erosion, the line of contact is some distance to the seaward from the stream. If the underlying older beds are very hard, the stream might continually shift itself along the line of contact, instead of cutting down into the hard beds below. A part of the old "lagoon portion," instead of cutting down into the underlying rocks, is shown as having been shifted down the dip of the newer beds, and as flowing parallel with the contact but to the seaward of it.

side, its lagoon might be shifted close up against the barrier. If, under these circumstances, this coast should be elevated and the shore line should be shifted some miles seaward, the "lagoon portion" of the resulting stream would be approximately parallel

to the strike of the rocks, and also to the upper and lower contacts of the particular group of strata formed, though several miles removed from either of those contacts.

On the other hand, a stream flowing parallel with the contact and not far removed from it might cut down completely through the series of strata by which its course was originally determined, and reach the older underlying rocks. Under such circumstances the newer beds through and along the edges of which the stream originally flowed, would in time be removed by erosion for some considerable distance from the line of contact, as shown in Fig. 4.

It is, of course, difficult to point with certainty to streams at present far inland that have had their courses originally determined in the manner suggested. This explanation offers itself, however, for streams that now flow parallel to and in the neighborhood of contacts between sets of beds of different ages, as also for streams flowing parallel to preëxisting coast lines. It is not improbable that many streams flowing with the strike of strata, and whose courses have been attributed to stream capture, owe these courses to the simple fact of their having been primarily established in that position as here suggested. Many such streams may be seen on any detailed geologic and drainage map of our eastern and southern coastal region, though they are by no means limited to such regions.

This explanation is suggested as a probable one in accounting for the sudden southwest deflection of the Delaware River at Bordentown, N. J., and the Potomac near Washington, and for the sudden turn of the Susquehanna into the upper portion of Chesapeake Bay, which may be considered as its extension.

The same explanation is suggested also in regard to the Tennessee River for the lower portion of its course where it flows northward through west Tennessee and Kentucky.

Black River, in Arkansas, flows for almost its entire length near the line of contact between Tertiary and Paleozoic rocks. This stream may have had its course originally established,

parallel to the old coast line in much the same way that Indian River, Florida, has its course fixed at the present time.

Many others could be mentioned, but these serve to show the character of the drainage that might be expected from the suggested causes.

It is not meant to imply by the foregoing remarks that all barriers that may be formed will exercise control on the ultimate drainage. Probably most of those formed are quickly destroyed as the shore line encroaches or recedes. It is hardly reasonable to suppose, however, that all barriers formed through past geologic ages have been disposed of thus easily.

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SEASON AND TIME ELEMENTS IN SAND-PLAIN FORMATION

THE SEASON ELEMENT

The term sand-plain is here used in the generally accepted sense, that is, to designate the sand delta formed at the mouth of a glacial stream as it issued from the ice margin into the standing waters of a glacial lake or into the sea. The bulk of such a plain is made up of a succession of layers of fine material sloping at an angle of 15° or more in the direction in which the current is moving, or away from the head of the plain. Upon these layers, which are known as fore-sets, rests a comparatively thin and nearly horizontal layer of coarse material known as top-sets. A third class of layers is represented by the horizontally stratified clay beds deposited in front of the constantly advancing fore-sets, and partly overlain by them in consequence of this advance. In addition there is sometimes a fourth, but much less extensive series of layers which have slopes just the reverse of those of the fore-sets. They are known as back-sets, and are formed, sometimes by the upward movement of the water as it leaves the ice and passes up and over the sand-plain,[1] and sometimes by the settling of the margin of the plain in consequence of the melting of the ice upon which it may have partially rested.

Wherever sand-plains have been exposed it has been found that the development of back-sets is insignificant, seldom amounting to more than twenty or thirty feet even in the largest plains. It is evident that if the margin of the ice were retreating during the construction of a sand-plain, the formation of back-sets by the first method would at once become a prominent feature of the deposition. It is doubtful if back-sets of this type have ever actually been noted, and back-sets of any sort are, as we have seen, of rare occurrence and slight development. This

[1] Bull. Geol. Soc. Am., Vol. I, 197.

shows conclusively that the forward growth of the delta must have been extremely rapid, for an ice margin bathed constantly by the waters of the sea or a glacial lake could not long remain stationary. That the time of growth was a short one was early urged by Davis and is generally admitted by those familiar with such deposits. Even in the case of many of the larger plains it seems clear that the time of growth should be measured by months rather than by years, and the assumption that they are the result of a single season's stream work is not unwarranted.

If this view is accepted, the question at once arises as to whether the plain represents the deposits of the whole, or only a part of the season of ablation. The first thought would naturally be that they represent the whole, but on more careful consideration this seems less probable. The observations upon sand-plains show that there was practically no backward melting of the ice during their formation. The retreat, then, must have taken place under conditions more favorable to the melting or breaking up of the margin of the ice sheet than those existing during the formation of the plains, and to maintain that the sand-plains represent the whole of the summer periods of melting would mean the reference of the periods of retreat to the winter season, a conclusion not in harmony with the laws of nature.

As an alternative, it might be considered that the sand-plains represent summers of only moderate warmth, while the periods of melting were characteristic of seasons of a considerably higher average temperature. The melting of the ice, the discharge of the glacial streams, and the amount of detritus, would all have been increased under such conditions. In reality we find that often only a slight deposition of sediments took place between the stages of sand-plain growth, especially when plains are but short distances apart, as in the case of the Barrington and Nyatt Point sand-plains, hereafter to be described. Here the intermediate area is practically free from deposits of an inter-sand-plain period, indicating that the retreat of the margin took place during a period when little detritus was being set free from the ice by ablation.

A consideration of the conditions obtaining during the closing stages of the ice sheet leads to the conclusion that the periods or steps of the retreat in the vicinity of the Barrington Plain were characteristic of spring, corresponding more or less roughly to the present months of March, April and May.

Following is a summary of the reasons: (1) The insignificant development, or complete absence of back-sets in the most typical sand-plains, show that the retreat was not characteristic of the summer period. (2) The fall represents a waning, and the winter a cessation of all the conditions that can in any way be regarded as favorable to the ice retreat. The retreat cannot, therefore, be regarded as characteristic of these periods. (3) Though the actual precipitation may have been no greater than in the winter months, precipitation in the form of rain probably reached its maximum in the latitude of northern United States during the months of early spring. It is well known that water attacks ice much more rapidly than air at the same, or even higher temperatures. The period of spring rains must, then, have been one of rapid ablation. (4) The precipitation of the winter months must have been mainly in the form of snow, which according to Upham, would reach a maximum within a comparatively short distance of the margin. Under the influence of the spring rains the deep snow must have rapidly melted, helping swell the glacial, and especially the superglacial streams to sizable turrents. The rapidity with which such superglacial streams cut into the ice is well shown by some of the superglacial streams of Greenland, which, though usually short and of small size, have often sunk to some considerable depth into the ice. Such streams near the margin of the waning ice sheet would have rapidly cut through the ice to the very bottom, leaving detached pieces of various sizes and shapes which, however, would melt with comparative rapidity. (5) The streams during the spring, being fed mainly from the melting snow or direct precipitation, would carry a proportionally small amount of sediment, and the detritus instead of being deposited at a single point, as in the case of the sand-plains, would be distributed

over a large area as an inconspicuous sheet. (6) In the summer the ice margin would become stationary and the deposition of the detritus, which was derived almost entirely from the ablation of the débris-laden ice, would be concentrated at definite points.

Although from the above considerations it seems reasonable to refer the shorter ice retreats between sand-plain stages to the spring months, it is probable that the longer retreats represent longer periods, perhaps in some cases years in length. In this case the absence of inter-sand-plain deposits may be more seeming than real, because of the sheet form of such deposits.

TIME ELEMENT

If the months of December, January, and February are eliminated, as there can be no doubt they should be, from the time of sand-plain growth, the retreat of the ice and the deposition of the plain must have taken place in the remaining nine months. The distance between sand-plain stages varied from a fraction of one up to several miles, and three months certainly seem none too long a time for such a retreat. If this be so, the sand-plains, or at least those of modern size, must have been formed in the six months still remaining.

A study of the conditions now existing in the larger glaciers of Alaska, showed at once that such a rate of deposition was by no means improbable. A calculation based on such conditions could not fail to be of interest, and would give valuable indication as to the probability of the general estimates. The results showed an unexpected and surprisingly close agreement with the estimates.

Basis of calculations.—Evidence as to the time of formation of sand-plains is afforded; (1) by the bulk of the sand-plain itself, and (2) by the bulk of the accompanying clays, which from their mode of formation, are known to be simultaneous in development and coextensive as to time. The time estimate is obtained by dividing the bulk by the daily discharge of sediment of the glacial stream. To find this discharge of sediment

it is necessary to know the area of the cross-section of the stream, the velocity of its flow, and the percentage of sediment carried. The first two values are indicated by the esker and the

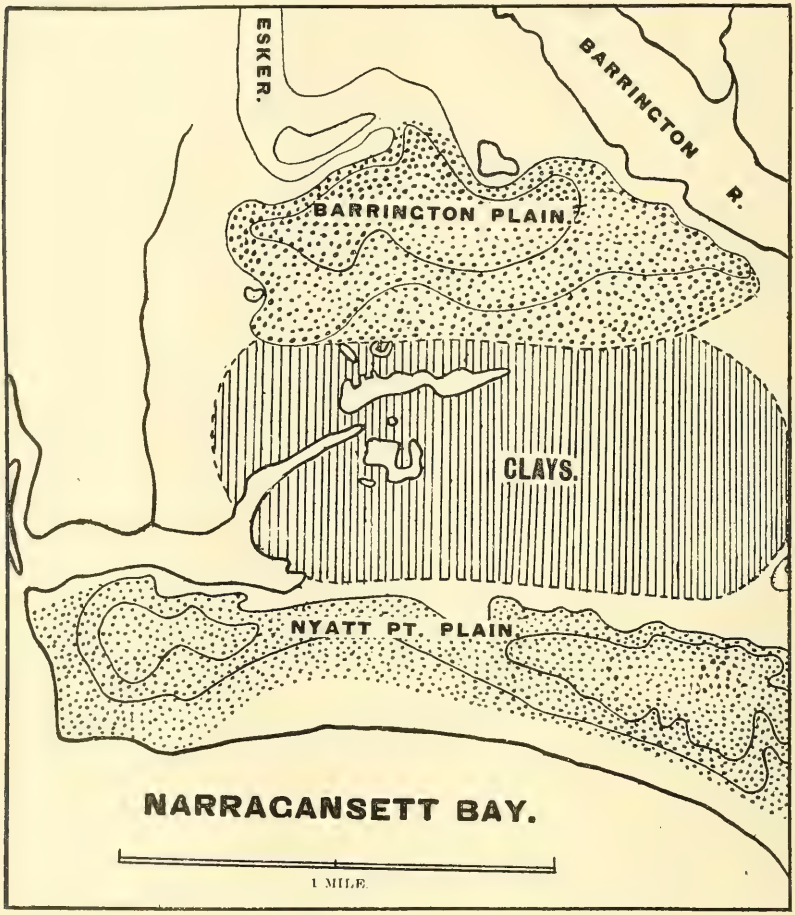

FIG. 1.—Map of Glacial Deposits, Barrington, R. I.[1]
Contour interval, 20 feet.

material of which it is composed. The latter must be estimated from observations upon glacial streams existing under similar

[1] The geology is taken from map given by Mr. J. B. Woodworth in Seventeenth Ann. Rept. U. S. Geol. Surv., Pt. I, Pl. LXII.

conditions at the present time. Such observations have been made by Wright, Reid, and others in regard to the fine sediments such as make up the so-called glacial clays, and it is upon these observations that the present estimates are based.

Locality selected. — Conditions favorable to a calculation of the time of formation from the extent of the plains, or their associated clays, are in almost every case wanting. In 1896, however, Woodworth described[1] and mapped a series of unusually typical deposits in the town of Barrington, R. I. A visit to the locality showed the conditions to be almost ideal, and admitting of calculations of some definiteness. The clays were selected as a basis of calculation in preference to the sand-plain itself, because of the greater number and reliability of the Alaskan observations upon this class of sediments.

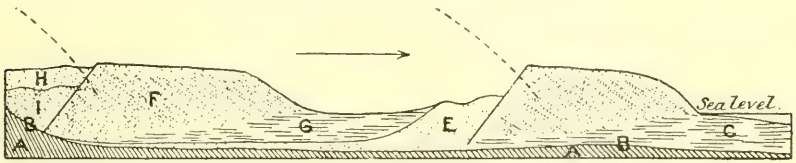

FIG. 2.—Section across Barrington, R. I., showing relations of clays to sand-plains. A, Terrane of Carboniferous age; B, Glacial drift older than Nayatt Point stage; C, Clays contemporaneous with the Nayatt Point sand-plain; E, Gravel and sands deposited upon the melting of the ice along the head of the Nayatt Point plain; F, Barrington sand-plain; G, Barrington clays; H, esker; I, gravel and sands laid down upon the melting of the ice back of the Barrington plain. — J. B. WOODWORTH: *Seventeenth Annual Report U. S. Geol. Surv., Part I, p. 987.*

Barrington clays. — These clays are exposed at the surface over an area of about six tenths of a square mile (Fig. 1). On the south the clays rest against the ice-contact slope of the Nyatt Point sand-plain, while on the north they extend as a gradually thinning wedge beneath the Barrington plain, reaching their northern limit approximately along the ice-contact slope of this latter plain (Fig. 2). The depth of the clays in the vicinity of the railroad, as shown by borings, is about sixty feet. With the exception of one slight break there is a ridge, partly till and

[1] Seventeenth Annual Report U. S. Geol. Surv., Part I, 987, 988; and Am. Geol., VOL. XVIII, 161–164, 391, 392.

partly of modified material, connecting the two sand-plains on the east, and having an average height of about forty feet. On the west there is no marked rise between the clays and the waters of the bay, the latter even at the present time having access to the clays by a fair-sized estuary. The surface of the clays is practically at sea level.

The clays, which vary from gray to blue-gray in color, are composed principally of quartz flour—the ultimate product of glacial scouring—with a comparatively slight intermixture of true clay. Their amount, allowing for the thinning out in various directions, and taking their specific gravity as 2.5, is found to be approximately 95.3 million tons.

Conditions at time of deposition.—The heights of the two sand-plains are about fifty feet and indicate a probable height of water at the time of their formation of at least forty feet above the present sea level. The ice on the north, the ridge on the east, and the Nyatt Point plain on the south would form an inclosed bay, with practically no opening except at the west. Here, however, there must have been an opening something like three fourths of a mile wide and thirty-five to forty feet deep connecting with the sea and allowing a more or less complete commingling of the salt and fresh waters.

Into this inclosed bay emptied, as indicated by its esker, a glacial stream 150 feet wide, with a probable depth of some twenty feet, and a velocity sufficient at times to move pebbles up to six inches in diameter. This would indicate a maximum velocity of a little over six feet per second, but the average material composing the esker would require a current certainly not over five feet per second. The discharge of such a stream would be 15,000 cubic feet per second.

The area of the cross-section of the outlet from the inclosed bay was about 138,000 square feet, or some forty-six times that of the glacial stream. If discharge took place uniformly through the outlet the velocity would have been one and one third inches per second. If the flow of the fresh water took place as a surface current, as would have been the tendency, a somewhat

greater velocity would have resulted, but not enough greater to have prevented the settling of the sediment. The ebb and flow of the tide, which is about four feet, would have decreased the outflow some 25 per cent. during flood tide, and increased it by a corresponding amount during the ebb.

The average distance through which the water would move in its passage from the mouth of the glacial stream to the outlet would be at least a mile. The current, which at the frontal slope of the sand-plain had a velocity, as indicated by the material deposited, of some eight inches per second, would decrease until certainly not over three inches per second at the outlet. Its passage would require fully four hours.

Sediment of glacial streams. — According to Helland,[1] as quoted by Reid,[2] the maximum sediment values of their respective regions are represented by the Unteraar glacier of Switzerland, which carries .142 grams per liter; the Langedal glacier of Norway, carrying .513 grams; and Alangordleck glacier of Greenland, carrying 2.37 grams. Both Wright and Reid found much more sediment in the waters from the Muir glacier of Alaska, the former recording a load which reduces to 12.12 grams per liter,[3] and the latter a load as high as 12.98 grams per liter.[4] As the Alaskan glaciers most nearly represent the conditions obtaining during the closing stages of the continental ice sheet, I have taken Reid's value of 13 grams (actual value, 12.98 grams) as a basis in calculating the time of formation of the Barrington clays.

In all probability the sediment discharged by the streams draining the continental ice sheet was even greater than that of the most heavily loaded glacial streams of today. I have sought to neutralize this difference as much as possible by applying as a mean value to the Barrington deposits the maximum value of the Muir glacier sediments.

[1] HEIM's Gletscherkunde, p. 363.

[2] Sixteenth Annual Report, U. S. Geol. Surv., Pt. I, p. 457.

[3] Ice Age in North America, p. 64.

[4] *Loc. cit.*, p. 454.

Rate of settling.—Recently, in connection with professional work for the Metropolitan Water Board of Massachusetts, Professor W. O. Crosby has incidentally had occasion to determine the rate of settling of the finer portions (*i. e.*, quartz-flour) of both the till and the stratified drift. No definite maximum limit has ever been fixed for the grains of quartz flour, but in the experiments in question this name was applied to that portion passing through a sieve of 170 meshes to an inch. The larger grains are about $\frac{1}{300}$ of an inch in diameter.

In the experiments, the results of which Professor Crosby has kindly placed at my disposal, 5 grams of the quartz flour were introduced at the top of a half-inch tube containing five feet of water. The time of settling was then taken. The results showed that fully 75 per cent. of the material settled within thirty minutes from the time of insertion, and in the majority of cases none whatever remained in suspension at the end of sixty minutes. In other cases a distinct turbidity, probably due to true clay, was still noticeable at the end of this time. This was determined by filtering and weighing, the amount varying from a mere trace up to 10 per cent.

The results show that even in fresh water the settling of quartz flour is very rapid, the greater part settling at a rate of at least ten feet per hour. In the inclosed bay in which the Barrington clays were deposited the water was salt, or at least decidedly brackish, and the rate of settling must have been much increased, especially in the case of the finer material, which, according to W. H. Brewer, will settle as much in salt water in thirty minutes as it would in as many months in perfectly pure water.[1] There can be no reasonable doubt, then, that practically the entire amount of sediment brought in by the glacial stream was deposited within the inclosed bay.

Statement of problem and results.—During a certain stage of the ice retreat from the region of Narragansett Bay, the area now covered by the Barrington clays stood at a level some forty feet below that at present existing, and was covered by a body

[1] Am. J. Sci., III, 29, p. 4.

of salt or brackish water which rested against the ice on the north, and was practically cut off from the sea on the east by a till ridge, and on the south by the Nyatt Point sand-plain. Into this body poured a glacial stream with a volume of some 15,000 cubic feet per second, and bearing a load which I have assumed as a maximum to be 13 grams per liter, amounting to 526,500 tons per day. From experiment it has been found that material like that of the Barrington clays settles very rapidly, indicating that practically the whole amount brought in by the glacial stream must have been deposited within the inclosed area indicated.

The amount of the clay is some 95.3 million tons. Dividing this by the daily discharge of sediment of the glacial stream, *the time of the deposition of the clays is found to be 181 days*, or almost exactly six months.

General application. — Though in the sand-plains of different localities, the proportion of sand and clay varies greatly, the Barrington deposits taken as a whole probably represent very nearly the average conditions. I am satisfied, therefore, that the results obtained in the case of the Barrington plain, though strictly speaking they are applicable only to this plain, represent fairly closely the time required for the formation of the *average* sand-plain. If, for the reasons given on a previous page (p. 454), the ice retreat is considered as taking place in the early spring, it would follow that these figures represent a maximum, rather than a minimum, time limit. In the case of large plains, however, with areas of several or many square miles it may be possible to consider the period of deposition as extending over more than one season of melting, there being in the meantime either no retreat of the ice margin, or a retreat so slight that the intervening space was completely filled, and the sand-plains united into a single compound plain.

Remarks. — One of the points most strongly emphasized by the results obtained, is the almost incredible amount of sediment discharged by the Barrington glacial stream during the few months of summer activity. The daily discharge of sediment by

this small stream, not over 150 feet in width, was equivalent to 40 per cent. of that of the Mississippi.[1]

The small amounts of the coarse material, compared with the amount of clay, is also a significant feature. It shows fully two thirds of the detritus brought in by the stream was of the finely comminuted quartz flour. The velocity was such that had the current come in contact with the subglacial till to any extent the percentage of coarse material would have been much greater. Its absence indicates, therefore, that practically the entire amount must have been derived from the ablation of the ice. The high percentage of the finer débris contained within the ice is certainly a striking feature.

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[1] J. B. WOODWORTH, *loc. cit.*, 162.

THE PETROGRAPHICAL PROVINCE OF ESSEX CO., MASS. GENERAL DISCUSSION AND CONCLUSIONS. V.

Analytical methods.—As far as was possible with the means at my disposal the methods advocated by Hillebrand[1] were followed, some slight modifications being necessary owing to lack of certain facilities in my laboratory. A word must be said in recognition of the high character of the work of the chemists of the U. S. Geological Survey. Petrologists generally are deeply indebted to them for the service they have rendered the science, not only by the investigation of methods and the very large amount of excellent work which they have done, but also for the high standard of excellence which they have set for other analysts to follow.

Ignition H_2O was determined in dry CO_2. It will be seen from the generally low summation of the rocks high in FeO that this did not entirely prevent oxidation under the conditions obtaining, but the error will not be high. The precipitation with ammonia was always made twice, and three times in the case of the basic rocks, in the presence of sufficient NH_4Cl. This is of the utmost importance, as pointed out by Pirsson[2] and Hillebrand,[3] on account of the tendency of MgO to be coprecipitated with the Al and Fe hydrates. Neglect of these precautions has rendered useless many analyses, but it is a point which is often overlooked. With one exception, MnO was not determined, since its amount was apparently small and its determination would have extended considerably the time necessary for an analysis, and hence lessened their number. Alkalis were, of course, determined by the Lawrence Smith method.

[1] Clarke and Hillebrand. Analyses of Rocks. Bull. U. S. Geol. Surv., 1897.

[2] Pirsson, Jour. Geol., Vol. IV, 688, 1896.

[3] Hillebrand, *op. cit*, p. 39.

It must be noted that throughout this paper the terms acid and basic refer only to the relative amount of SiO_2, no connotation of the amounts of the other oxides being implied.

Use of the term petrographical province.—The idea which underlies the general use of this term is that of a region of igneous rocks which possess in common certain characters, structural, mineralogical, or chemical, and in which the characters may vary continuously from one end to the other of the series of rocks represented. The term is usually applied to large areas embracing several centers of igneous activity, which, by their similarity in character, may be presumed to be related. Its application in the title of this paper is somewhat restricted, and therefore open to criticism, but seems justified on the grounds of convenience, the evident relationship of the rocks, and the fact that this region may serve as the type of the still larger New England one.

Chemical characters.—In Table I are given my analyses of the rocks of Essex county, with one by Dr. Eakle, and in Table II the molecular amounts of the various oxides. It is to be borne in mind that all references to the relative amounts of the oxides are to their molecular amounts, and not to their percentages as obtained in the analyses.

The range in composition is very great, the rocks varying from basic gabbro with 44 to acid granite with 78 per cent. of SiO_2. Al_2O_3 varies considerably and is notably higher toward the basic end. The total amounts of iron oxides are rather high, Fe_2O_3 being low and varying little, while FeO is higher, especially so in the basic rocks. MgO and CaO behave alike, being low in the more acid rocks, and suddenly much higher in the basic. The alkalies are abundant, Na_2O more so than K_2O, but, on the whole, do not vary as much as the other constituents.

The rocks as a whole are rather acid, *i. e.*, they contain more SiO_2 than most similar types elsewhere. The granite is decidedly an acid one, the foyaites more acid than most nepheline-syenites, and the same is true of the pulaskites, the akerite

and nordmarkite, the tinguaite, sölvsbergite, and paisanite. In the basic rocks, on the other hand, the opposite seems to hold goo d, that they are more basic than usual.

In the next place they are rich in both alkalis, and Na_2O is constantly greater than K_2O. On the whole, however, Na_2O does not predominate to such an extent as to stamp the region as essentially one of soda rocks, but is sufficiently predominant to determine the character of the types, as shown in the mineralogical composition.

In general the rocks are rich in iron oxides, FeO being especially, and in some cases abnormally, high. It may be mentioned that TiO_2 is high, comparatively speaking, and that BaO seems to be absent.

The province as a whole then, may be characterized as one of rocks which are more acid or more basic than normal, high in alkalis, with Na_2O predominating over K_2O, high in iron oxides, especially FeO, rather high in Al_2O_3, and low in MgO and CaO.

Mineralogical characters.—We find the main chemical features well expressed in the general mineralogical composition. Corresponding to the high SiO_2 and alkalis, the prevailing feldspars are albite and orthoclase, with quartz-syenites abundant. The albite molecule is very abundant, giving rise to the characteristic microperthites and the albitic syenites of the litchfieldite and pulaskite types. At the same time the soda-hornblendes and soda-pyroxenes are common. The low CaO forbids the formation of much lime-soda feldspar, which we find to be rare, and even in some of the basic rocks the plagioclase is more albitic than usual.

The paucity in MgO is of great influence. Olivine is rare even in the basic rocks. A striking peculiarity in this connection is the replacement of the deficient MgO by FeO. This gives rise to the presence of varieties of minerals normally magnesian, but which are here largely ferrous instead. This is exemplified by the abundance of the MgO-free biotites, lepidomelane and cryophyllite, as well as the occurrence of the

purely ferrous olivine, fayalite[1] in the granite, and the presence of the MgO-free "glaucophane" molecule in the blue hornblendes[2] of the region.

Discussion of oxide ratios.—In Table II are given, below the molecular amounts, several oxide ratios, which we may next examine, since they serve to differentiate the rocks of the region into groups.

$\frac{Na_2O}{K_2O}$. This ratio is constantly greater than unity, as we have seen, though often closely approaching it. A striking feature is that in ten or eleven cases it is either exactly or very near a whole number; 1 : 1, 2 : 1, 3 : 1, or 6 : 1. In ten others it closely approximates to multiples of a half; 1½ : 1, 2½ : 1, 3½ : 1, or 6½ : 1. In only three or four cases does it differ more than about .12 from such figures. There seems to be a tendency for Na_2O and K_2O to exist in stoichiometric ratios with respect to each other. The same is true elsewhere, notably in the Christiania region, where Brögger[3] connects it with the tendency of the alkalis to such ratios in nepheline and soda-orthoclase. Such ratios, however, in igneous rocks are by no means general.

When we examine this ratio in the various rocks we see that it is characteristic of certain rock groups. In the granite, the quartz-syenite-porphyry and the quartz-syenites it is quite constant, varying only from 1.09 to 1.17. In the aplite dike it is a little higher, about 1.5. In the keratophyre and rhyolite it is still higher, 1.40 and 2.20. As we go toward the basic end the ratio increases, being 1.7 and 2.1 in the pulaskites, 2.2, 2.5, and 3.6 in the sölvsbergites and biotite-tinguaite, and 3.0 in the foyaites. In the basic rocks, from diorite down, the ratios are constantly high, varying from 2.6 to 6.6, and is also high, 6, in the analcite-tinguaite.

[1] PENFIELD and FORBES: Am. Jour. Sci. (IV), I, 129, 1896.

[2] H. S. WASHINGTON: Am. Jour. Sci. (IV), VI, 179, 1898.

[3] BRÖGGER: Eruptivgesteine der Kristianiagebietes. I, 165, 1894, and III, 249, 1897.

It will be seen that in what are obviously connected series of rocks there is a regular variation in one direction, an increase toward the basic end. The most striking instance is the paisanite-tinguaite series, in which the ratios are 1.23, 2.17, 2.47, 3.62, and 5.97. Also in the pulaskite-foyaite-essexite series, where the ratios are 1.71, 2.09, 3.00, 2.98, and 3.64. The granite, quartz-syenites, diorites, and gabbros show the relation less well, though even here the ratio is markedly higher in the basic members.

These observations leave no doubt of the fact that in Essex county Na_2O increases relatively to K_2O as SiO_2 decreases. This agrees with the Christiania region, where Brögger[1] shows that in the grorudite-tinguaite series the same holds good. In both cases the effect is due chiefly to increase in Na_2O relatively to SiO_2, K_2O remaining comparatively stationary. The line giving the ratio of $Na_2O : SiO_2$ will show this for Essex county. Such a variation is not universal, as in other regions exactly the contrary obtains,[2] the K_2O increasing as SiO_2 decreases.

It is evident, therefore, that Na_2O and K_2O differentiate with respect to each other, a fact to which Pirsson has already called attention.[3] This is of theoretical interest since it indicates that, notwithstanding their general similarity, there is a difference between the two alkalis in their functions in igneous rocks, a subject which space does not permit of being treated here.

$\frac{FeO}{Fe_2O_3}$. The variations in this ratio are far greater than in the preceding, ranging from 0.37 to 16.0, but examination reveals certain regularities. It is very high in the granite, aplite, quartz-syenite, and porphyry, and in all the basic rocks. It will also be observed that it is higher in the dike rocks than in their corresponding plutonic forms. It is lower in the paisanite and sölvsbergites, still lower in the pulaskites and foyaites, as well as

[1] BRÖGGER: *op. cit.*, Vol. III, p. 249, note 1, 1897.

[2] PIRSSON: Bull. 139 U. S. Geol. Surv., p. 138, note 5, 1896. HARKER: Geol. Mag., Vol. IX, 203, 1892.

[3] PIRSSON: Bull. 139 U. S. Geol. Surv., p. 138, 1896.

in the rhyolite and keratophyre, and lowest of all in the tinguaites.

It is evident, granting that these relations are not fortuitous, which the number of analyses seems to preclude, that this ratio does not vary with the SiO_2, but seems to be dependent here on the general character of the magma from which the rocks solidified. Grouping these roughly into two classes according to their general characters we may say that the ratio is high in the granito-dioritic group and low in the foyaitic.

It is, it must be confessed, somewhat surprising to find such a connection between the ratio of the two iron oxides and the petrographical character of the rocks. Is it indeed the fact that there is such a difference in behavior between the two oxides? Do they really differentiate with respect to each other, or is the relation only apparent and due to other causes, such as possible oxidation of the ferrous iron in the foyaitic rocks? In the flow rocks the ratio is low and it seems possible that their solidification at the surface may have induced oxidation. But all the other rocks are abyssal or hypabyssal, so that such an action would seem to be excluded, or at least equally effective in each. We have also seen that the granito-dioritic dikes show a uniformly higher ratio than their plutonic analogues. On the whole we seem driven, as far as the data at hand allow us to decide, to the conclusion that the two oxides differentiate with respect to each other and that their ratio is in some way connected with the composition of the magma.

In connection with this ratio we may note the interesting case of Nos. XV and XIV, the tinguaite and sölvsbergite, whose composition is very similar, the total iron oxides being about the same. In the tinguaite the high Fe_2O_3 (ratio 0.52) has conditioned the formation of aegirite, while in the sölvsbergite the high FeO (ratio 3.31) has conditioned the formation of glaucophane-riebeckite as the colored mineral.

$\frac{Na_2O+K_2O}{SiO_2}$ This ratio has been recently employed by Iddings[1] in the investigation of the relationships of rocks. Here

[1] IDDINGS: JOUR. GEOL., Vol. III, 956, 1895, Vol. VI, 96, 189, Vol. VI, 219, 1898.

it corresponds in a general way with the grouping already used. In the acid rocks, from granite to akerite, the ratio is low and fairly constant, varying only from .088 to .121. In the foyaitic rocks from glaucophane-sölvsbergite to analcite-tinguaite, it is much higher and also fairly constant, from .156 to .228. In the basic rocks the ratio is again low, the essexite alone showing the high ratio of .166, analogous to that of the foyaites, as was to be expected. The ratio of the hornblende-gabbro (.112) is also in accord with its transitional character between the diorites and essexite.

A large number of other ratios have been examined, but without any very significant results. The only one worth mention is that of $Al_2O_3+Fe_2O_3 : CaO+Na_2O+K_2O$. In the more acid rocks, from pulaskite up, this approximates closely to unity, but below this there are some other wide variations, the sesquioxides being deficient, except in the foyaites.

The rock series.—Without going further into details, we may divide the rocks of Essex county into the following series as defined by Brögger.[1]

The first may be called the *granito-dioritic*, and embraces the granites, quartz-syenites, quartz-diorites, diorites (which are partly monzonitic), and gabbro. These are characterized mineralogically by the presence of microperthite (albite and orthoclase) in the more acid members and plagioclase with some alkali-feldspar in the basic, and by iron-micas (in the more acid) and green and brown hornblendes and pyroxenes. Chemically they show comparatively low ratios of Na_2O to K_2O and $Na_2O + K_2O$ to SiO_2, and high ratios of FeO to Fe_2O_3.

To this is related a series of dike rocks, including the aplites and microgranites, quartz-syenite-porphyry, and, at the basic end, probably a part of the diabases. These dike rocks possess chemical and mineralogical characters similar to those of the preceding series.

The next prominent series is the *foyaitic*, embracing the pulaskite, litchfieldite, and essexite, and characterized by the

[1] Brögger: Eruptivgest. d. Kristianiageb. Vol. I, p. 169, 1894.

abundance of the albite molecule, lack of lime-soda feldspars, and presence of nepheline, aegirite, and blue glaucophane-riebeckite or brown barkevikite. These rocks show high Na_2O : K_2O : and $Na_2O + K_2O$: SiO_2 ratios and low FeO : Fe_2O_3.

Related to this series are the dikes of the sölvsbergite-tinguaite series, and of paisanite, also possibly the camptonitic dikes. These show chemical and mineralogical characters analogous to those of the foyaitic series, but vary far more in composition.

These four series, which are very well defined, include nearly all the rocks examined. Among the exceptions the hornblende-gabbro occupies, as we have seen, a position intermediate between the diorites and essexites, and may be reasonably regarded as a transitional and connecting form. The flow rocks are abnormal. In certain respects they seem to be allied with the granito-dioritic rocks, while other characters suggest affinities with the foyaites. The question is a difficult one to decide. The orbicular syenites, which are present in very small amount, are almost certainly related to the granito-dioritic series, though lack of an analysis leaves the question uncertain. By its mineralogical characters and by its ratios the Quincy granite belongs to a foyaitic series, forming the most acid member of it, and corresponding to the paisanites among the dike rocks. As it belongs to the Blue Hills Complex, quite outside our region, it will not be discussed further.

Relations of the various types.—As a preliminary to the determination of the genetic connection of the various rocks, it will be well to obtain some idea of the relative amounts of the different types represented. For obvious reasons it is, of course, not possible to do this with certainty or accuracy. If we assume that the areas shown on the geological map are dependent on the relative volumes (which may or may not be the case) we shall get an estimate, which, though very far from being accurate or wholly satisfactory, may be considered provisionally to express the relation in a general way, and which will probably be sufficient for our present purpose.

An examination of Mr. Sears' map, together with a consideration of my own observations, permits me to estimate, *in a very rough way*, the relative percentage areas given in the following table, in which are also given the relative volumes, reduced to percentages, calculated from these data. This estimate, it must be observed, includes only the main area of igneous rocks, excluding the area of sedimentaries and gneisses, etc., which covers the western part of the county, as well as the quartz-diorite area near Newburyport, since the northerly extension and connections of this are unknown to me.

Rock	Area, %	Volume, %
Granite	30	37.2
Quartz-syenites	24	26.4
Diorites	28	33.4
Foyaites	2	0.6
Essexite	1	0.2
Gabbro	1	0.2
Acid Dikes	1	0.2
Basic Dikes[1]	3	1.2
Rhyolite[2]	10	0.6

It will be seen that the granites and quartz-syenites constitute nearly two thirds of the total, the diorites[3] one third, while all the others make up only three per cent. This result is of special interest since this region is generally regarded by petrographers as essentially one of nepheline-syenites. They occur, it is true, but form only a small, though important, part of the complex.

[1] Shaler (*op. cit.*, p. 583) estimates the area of the dikes of Cape Ann at 5 to 10 per cent. As dikes are apparently less abundant elsewhere I have reduced this considerably, especially as my observations lead me to think it too high.

[2] As these are flow rocks their depth will be small compared to their area, and I have therefore estimated their volume at only a tenth of that calculated on the basis of the other rocks.

[3] I have recently received from Mr. Sears a large and representative collection of the diorites of the main western Ipswich-Danvers area. Although time is lacking for proper microscopical and chemical study, they are evidently quite basic, and to all appearance approximate very closely to those already described, chemically and mineralogically.

Assuming that the figures given in the table above are roughly true (which is quite hypothetical), it will be of interest to calculate the composition of the magma as a whole. The results of this calculation, which are admittedly crude and of little reliability on account of the character of the data employed, are as follows:

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O, etc.
65.3	1.0	14.5	1.2	4.6	1.7	3.6	3.7	4.0	0.4=100.

The result corresponds in general with the idea of the magma derived from examination of the analyses, though it is perhaps somewhat higher in MgO and CaO, and hence more monzonitic, than we might have expected. Of the rocks analyzed it approaches most closely to that of the akerite (No. X), but it shows less SiO_2 and alkalies, and more MgO and CaO than this. A rock of this composition would probably be found among the more basic akerites or more acid diorites.

Leaving this aside for the present it will be evident that the main course of differentiation (assuming that such has taken place), has been to form a large series of granites, quartz-syenites, and diorites, which pass into one another more or less gradually through transition forms. Among these there is a quite gradual gradation of the oxides, as will be seen on reference to the table of analyses. A rather peculiar feature is the increase of Al_2O_3 in the basic members, which is quite unusual. Parallel series from other regions analogous to this might be mentioned, but it seems scarcely worth while to do so.

The series of granito-dioritic dikes, which correspond so closely both mineralogically and chemically to the granolites, must be classed as aschistic[1], *i. e.*, which are not separate differentiation forms of their magmas, but only dike forms of the partial magmas which solidified elsewhere as granolites.

The foyaitic series presents a somewhat different problem. These rocks are evidently connected genetically with the main

[1] BRÖGGER: *op. cit.*, Vol. I, p. 125. I am in some uncertainty in thus rendering into English BRÖGGER'S words *aschist* and *diaschist*. The termination -ic would seem to be better than -ous or -ose, which latter is already in use in schistose, denoting structure.

series, both on geological grounds and petrographical, such as the transition forms between the essexite and diorites. They represent, however, a distinctly different magma; one not only more basic, but richer in Na_2O and Al_2O_3 and poorer in CaO, MgO, and FeO. They are also notable for the fact that considering their very small amount they are relatively more differentiated than the main magma. This is in accordance with observations on nepheline-syenite regions elsewhere, which, it is well known, carry not only a very great number and variety of rare component minerals, but also show a comparatively large number of rock varieties.

Since it has been shown that in the granito-dioritic series Na_2O tends to increase relatively to K_2O as SiO_2 decreases, and at the same time as it increases inversely as SiO_2, it follows that in the course of a differentiation of such a magma there should be an enrichment of Na_2O at the basic end. The rocks of the foyaitic series may then be held to represent the further differentiation products of such a basic, soda-rich portion of the main magma, this further differentiation taking place in accordance with the tendency of magmas rich in soda to differentiate, while in the more acid portions the relations would remain more simple. This explanation is essentially that of Pirsson[1] to account for the phonolitic dikes of the Judith Mountains.

Lack of space forbids the full discussion of the foyaitic dike rocks, comparing them with the main types as Brögger has done, but the evidence goes to show that the paisanite, sölvsbergites, and tinguaites are probably to be regarded as diaschistic dikes, i. e., further differentiation products of the foyaitic magma, and not simply dike forms of this. This is analogous to the Christiania region, where Brögger[2] has shown that the dikes of the grorudite-tinguaite series are diaschistic.

The differentiation probably laccolithic.—We have now to examine the question as to where the differentiation of the Essex county magma took place. Are the rocks, as we see them, due to

[1] PIRSSON: Eighteenth Ann. Rep. U. S. Geol. Surv., p. 573, 1898.

[2] BRÖGGER: *op. cit.*, p. 127 ff.

successive injections of liquid magmas and the differentiates[1] of a more deeply seated magma, only part of which was released from the reservoir, or are they the differentiates *in situ* of a body of magma which was injected in a more or less homogeneous condition from below? Is the differentiation, in other words, "deep magmatic," or "laccolithic?"[2] Very thorough and careful field study is necessary to decide this question, study which it has not been possible for me to undertake. At the same time, certain considerations seem to point to the conclusion that the differentiation at Essex county was laccolithic, and that the complex may possibly be regarded as a laccolith. I can only point out very briefly the facts on which this conclusion rests, leaving the further study and settlement of the question to others.

Comparatively very few differentiated laccolithic masses have been studied, but those which we know best show a basic border and more acid interior, with, in some cases, an intermediate zone of medium composition. Prominent examples of these are Brandberget, in Gran;[3] Carrock Fell[4] in England, and the especially beautiful and instructive ones described by Weed and Pirsson, notably, Square Butte,[5] Yogo Peak,[6] and Bear Paw Peak[7] in Montana.

On looking at the geological map of Essex county,[8] it is seen that the main granite area is to the east, extending in large patches from Cape Ann westward, and ending in this

[1] I use this term as synonymous with and more convenient than "differentiation product." It is formed analogously to the word *solute*.

[2] BROGGER: Quart. Jour. Geol. Soc., Vol. L, p. 29 ff., 1894, and Erupt. gest. d. Christ. geb., Vol I, p. 153, 1894.

[3] BROGGER: Quart. Jour. Geol. Soc., Vol. L, p. 31, 1894.

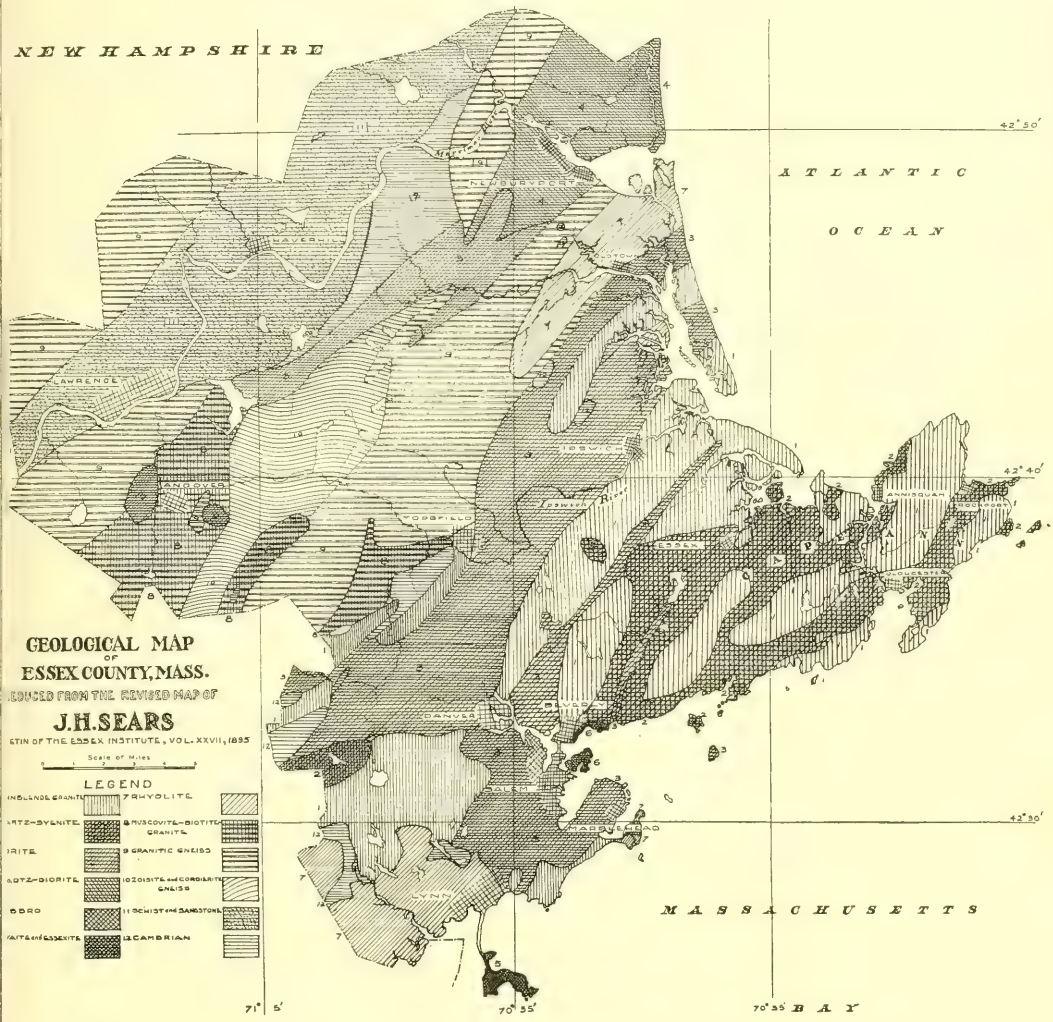
[4] HARKER: Quart. Jour. Geol. Soc., Vol. L, p. 311, 1894, and Vol. LI, p. 125, 1895.

[5] WEED and PIRSSON: Bull. Geol. Soc. Am., Vol. VI, p. 389, 1895.

[6] WEED and PIRSSON: Am. Jour. Sci. Vol. L, p. 467, 1895.

[7] WEED and PIRSSON: Amer. Jour. Sci., Vol. I, p. 351, 1896.

[8] The map here given is copied from the revised one of Mr. Sears, some omissions being made on account of the greatly reduced scale. An attempt has been made to show approximately the small foyaite area along the Beverly Shore.


NEW HAMPSHIRE
ATLANTIC
OCEAN
MASSACHUSETTS
BAY
42° 50′
42° 40′
42° 30′
71° 5′
70° 55′
70° 35′
GEOLOGICAL MAP
OF
ESSEX COUNTY, MASS.
REDUCED FROM THE REVISED MAP OF
J.H. SEARS
BULLETIN OF THE ESSEX INSTITUTE, VOL. XXVII, 1895
Scale of Miles
LEGEND
7 RHYOLITE
8 MUSCOVITE-BIOTITE GRANITE
9 GRANITIC GNEISS
10 ZOISITE and CORDIERITE GNEISS
11 SCHISTS and SANDSTONE
12 CAMBRIAN

direction in a broad zone which runs north-northeast from Beverly to Ipswich. Interspersed with the granite and surrounding some of the smaller areas is quartz-syenite, which is not met with west of the granitic zone, except in two small patches. West of the granite area, and forming also a broad zone running north-northeast, is the main area of diorite, which curves around to the south, forming the Salem area, and is also met with as strips and tongues in the granite areas. West and northwest of the diorite are found sedimentary and metamorphic rocks, of which something will be said later. The small area of foyaitic rocks lies near Salem, south of the western parts of the granite and quartz-syenite areas. The gabbro is only met with at the extreme south, on the small promontory of Nahant with patches of metamorphosed Cambrian sedimentaries. To the south near Lynn, and north near Newburyport, are areas of rhyolite, a small patch of which is also found at Marblehead Neck, southeast of Salem.

There is then a rather regular arrangement, the acid rocks being to the east and the basic diorites surrounding them to west and south, lying on the outside next to the nonigneous rocks. This is suggestive of the arrangement of the rocks in the ordinary type of differentiated laccolith.

In the next place, according to Mr. Sears' map and his description of the sedimentary rocks,[1] we find that the dips of the sedimentaries and metamorphosed rocks, which form the western part of the county, are in general to the northwest or north-northwest, *i. e.*, away from the igneous area. This is also suggestive of a laccolithic mass, and the few small areas of sedimentaries metamorphosed by contact with the igneous rock, which are met with here and there through the igneous areas, may be considered to be remnants of the original cover. In fact, Mr. Sears, himself, indicates the conclusion that the mass is an anticlinal laccolith, when he says:[2] "The position of these two metamorphosed crystalline sedimentary beds signifies that

[1] SEARS: Bull. Essex Inst., Vol. XXII, p. 1, 1890.

[2] SEARS: Bull. Essex Inst., Vol. XXIII, p. 15, 1891.

they are remnants of an anticlinal fold of the Cambrian sediments, perhaps produced by the intrusion of the eruptive granite magma from beneath them."[1]

A further fact, which is in favor of laccolithic differentiation, is the radical difference of opinion of the two observers, Wadsworth and Sears, who are best acquainted with the region, as to the order of succession of the igneous rocks. Leaving the dikes out of consideration, and adopting the nomenclature of this paper, Wadsworth[2] gives it as follows, beginning with the earliest: gabbro and diorite, quartz-syenite, nepheline-syenite, granite, and rhyolite. Sears,[3] on the other hand, gives granite, quartz-diorite, essexite, diorite, nepheline-syenite, and quartz-syenite, gabbro, rhyolite. This argument is not conclusive, since the differences of opinion are perhaps explicable on the ground of lack of good exposures, etc., but in the case of two good observers, who made a careful study of the region, they are suggestive of the fact that there is no "order of succession" in the usual sense of the term, and which we would not expect to find in the case of a differentiating laccolithic mass of magma.

Lastly, it may be mentioned that the rocks are just what we might expect to find as the differentiates of a magma, such as this was, when laccolithically differentiated. The transition types which exist between the various members, and the "schlieren," such as those in the diorite of Marblehead, are also in favor of this hypothesis, as is also the greater abundance of dikes in the granites as compared with the diorites, since it seems reasonable to suppose that many cracks formed from below would penetrate the granite, and not the overlying diorite zone.

Several objections may readily be brought against this hypothesis, among which may be mentioned, the asymmetric character of the complex and the absence of quartz-syenite between the granite and diorite, where we should expect to find it. The first

[1] A similar structure is apparently suggested by HOBBS (Amer. Geol., Vol. XXII, p. 110, 1899) for the area about Waltham, southwest of our region.

[2] WADSWORTH: Geol. Mag., p. 209, 1885.

[3] SEARS: Bull. Essex Inst., Vol. XXVII, p. 109, 1895.

objection may be met with the fact that such asymmetric laccoliths are known, and are to be looked for in certain conditions of the surrounding strata.[1] Further, the presence of the coastal fault line and the Atlantic Ocean to the east is a sufficient explanation for the disappearance of a large part of the mass on this side.[2] The irregularity of the quartz-syenite is a more serious objection, and is, perhaps, best explained by the admitted fact that the laccolith must have been of a decidedly irregular shape, owing to the conformation of the strata into which it was intruded. It is possible, also, that considerable faulting may have taken place. The microscope shows that most of the rocks have been subjected to pressure, such as would be consequent on crustal movements. It must be noted that I am here using the term laccolith in a broad sense, as Cross and Pirsson have done to include "all thick lenticular (in this case elongated) masses which have domed up the strata, and have over the greater part of their area a roof of sediments"[3] (here largely disappeared through erosion, glacial, and otherwise). The actual presence of this last feature is not essential to the idea, since any cover may be removed by erosion without affecting the original character of the mass.

It may also be remarked that, as far as can be seen, the course of differentiation would be the same whether, as in a true laccolith, the intruded magma bulged up the overlying strata, or entered an arch space formed otherwise.[4] From the petrological standpoint the mechanics of the process are of secondary importance. The chief point of my suggestion is that the differentiation was laccolithic and of a mass *in situ*, and not deep magmatic, and the rocks the results of successive intrusions. In the one

[1] W. Cross: Fourteenth Ann. Rep. U. S. G. S., p. 236 ff, 1895. Pirsson: Eighteenth Ann. Rep. U. S. G. S., pp. 555, 581, 1898.

[2] Mr. Sears (Bull. Essex Inst., Vol. XXII, p. 16, 1890) notes the occurrence of Cambrian limestone at Jeffrey's Ledge, in the Atlantic Ocean, about twenty miles east of Cape Ann.

[3] Pirsson: *loc. cit.*, p. 581.

[4] For an example of the latter cf. Watts: Rep. Brit. Assoc. 1886, p. 670 and Proc. Geol. Assoc., 1894, p. 341.

case the rocks are all genetically connected, in the other possibly not.

Conclusion and summary.—My view, then, of the structure of the complex and genetic relationships of the rocks of Essex county is as follows. The igneous area represents possibly a section through an elongated, irregular, anticlinal, laccolithic mass, with a N. N. E.—S. S. W. trend, intruded into already disturbed Cambrian strata. The plutonic igneous rocks represent the products of a laccolithic differentiation in this magma, and not successive intrusions. The magma was rather acid, rich in alkalies and ferrous iron, and possibly did not differ materially from the calculated composition given on page 472. This course of differentiation produced primarily and most abundantly the granites, quartz-syenites, and diorites, with their corresponding aschistic dikes as *Nachschube*. A secondary local differentiation of the more basic differentiates of this process gave rise to the foyaites and essexites, while the rocks of the paisanite-tinguaite series are probably diaschistic dike forms of these. At a much later period, after erosion had removed much of the covering of the granolites, the rhyolites were erupted, from some unknown vents. Lastly, here, as so often elsewhere, the diabases were injected into the much cracked complex.

Comparison with other regions.—So much space has been devoted to the previous discussion that a few words must suffice for this topic. From the references to the Christiania region throughout the paper and comparison of the analyses, the general correspondence between the two is evident. There are differences in details, such as the more acid and somewhat less soda-rich character of the Essex county rocks, abundance of diorites here and of laurvikites and laurdalites in Norway, etc. But it may be said that the general course of differentiation was essentially much the same in both, a fact which supports the theory that the variations of rocks are largely subject to physico-chemical laws, and are not fortuitous and due to the composition of the surrounding rocks and other external circumstances, as Johnston-Lavis and Becker would have us believe.

A comparison could also be instituted with the other igneous rocks of the New England region, going to show that great similarities exist. But our knowledge of most of the other igneous regions of New England and Canada is so scanty that the time does not seem ripe for this. It will be sufficient to note that some of the rocks of Essex county show great analogies with, for instance, those of Litchfield, Maine, and Red Hill and Mt. Ascutney, New Hampshire. Farther west, in the Adirondacks and near Montreal, the character of the magma seems to be different, as has been pointed out recently by Cushing,[1] though there are many resemblances.

HENRY S. WASHINGTON.

[1] H. P. CUSHING: Bull, Geol. Soc. Amer., Vol. X, p. 191, 1899.

TABLE I.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
SiO_2	77.61	77.14	76.49	73.93	71.40	70.64	68.88	68.36	67.35	66.60	64.28	63.71
TiO_2	0.25	0.29	trace	0.18	.....	0.90	0.19	trace	0.60	0.76	0.50	trace
ZrO_2	.....	.....	.....	.....	.....	.....	.. ..	.....	.....	.....	.....	.....
Al_2O_3	11.94	12.24	11.89	12.29	14.76	15.34	14.77	16.58	15.05	15.05	15.97	18.30
Fe_2O_3	0.55	0.29	1.16	2.91	1.68	1.83	0.64	0.90	1.23	1.07	2.91	2.08
FeO	0.87	1.04	1.56	1.55	0.72	1.10	4.64	3.24	4.76	4.42	3.18	2.52
MnO	trace	trace	trace	trace	trace	trace	trace	trace	0.05	trace	trace	trace
MgO	trace	0.06	trace	0.04	0.55	0.52	0.37	0.45	0.03	0.36	0.03	0.09
CaO	0.31	0.35	0.14	0.31	0.10	1.24	1.74	1.85	0.55	2.21	0.85	1.18
BaO	.....	.....	.....	none	.....	.....	.....	.....	.....	none	none	.....
Na_2O	3.80	4.64	4.03	4.66	4.79	5.23	3.83	3.97	4.42	4.03	7.28	6.39
K_2O	4.98	4.47	5.00	4.63	5.16	3.55	4.97	5.27	6.08	5.42	5.07	6.21
H_2O (110°)	trace	trace	0.12	.....	.....	0.14	0.06	0.18	0.16	.....	.....	0.09
H_2O (ignit)	0.23	0.14	0.38	0.41	1.46	0.38	0.24	0.17	0.17	0.41	0.20	0.17
P_2O_5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.08	.....
	100.54	100.66	100.77	100.91	100.62	100.87	100.33	100.97	100.45	100.33	100.33	100.74
Sp. Gr.	2.618		2.650	2.642		2.632	2.696		2.690	2.612	2.703	2.686
at	18°C.		13°C.	22°C.		12.5 C.	12 C.		17°C.	17°C.	22°C.	12°C.

TABLE I — *Continued.*

	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV
SiO_2	63.09	61.05	60.05	59.31	58.77	56.75	51.82	47.12	46.99	46.59	45.32	43.73
TiO_2	0.45	0.34	0.11	0.32	0.31	0.30	2.15	3.27	2.92	1.41	1.94	4.23
ZrO_2	0.06	.....	.....	.....	0.11	.....	.....	.....	.....	.....	.....	... .
Al_2O_3	18.50	18.81	19.97	22.50	22.64	20.69	17.06	14.43	17.94	17.55	18.99	20.17
Fe_2O_3	2.90	2.02	4.32	1.93	1.54	3.52	1.97	3.33	2.56	1.68	3.78	4.32
FeO	1.36	3.06	1.04	1.40	1.04	0.59	8.60	11.71	7.56	10.46	9.78	6.93
MnO	trace	trace	0.79	trace	trace	trace	trace	.....	.....	.....	.....	.....
MgO	0.16	0.42	0.23	0.17	0.19	0.11	4.87	6.05	3.22	7.76	4.68	3.91
CaO	1.00	1.30	0.91	0.46	0.74	0.37	8.59	9.63	7.85	10.64	9.19	10.99
BaO	.....	none	.....	.....	none	none	.....	.....	none	.....	.....	.....
Na_2O	7.25	6.56	7.69	7.98	9.62	11.45	3.44	2.58	6.35	3.31	3.78	2.42
K_2O	5.23	6.02	3 24	4.08	4.89	2.90	1.77	1.11	2.62	0.72	2.12	1.45
H_2O (110°)	0.21	.....	0.15	0.15	0.07	0.04	0.11	0.28	.....	0.10	0.09	0.08
H_2O (ignit)	0.62	0.78	1.26	1.12	0.90	3.18	0.20	0.34	0.65	0.07	0.31	1.02
P_2O_5	.....	.....	Cl=0.28	.....	.....	Cl=0.28	.....	.....	0.94	.....	.....	0.15
	100.83	100.36	100.04	99.42	100.82	100.18	100.58	99.85	99.60	100.29	99.98	99.40
Sp. Gr.		2.655	2.708	2.599	2.596	2.474		3.072	2.919	3.047	2.975	3.058
at		12°C.	....	12 C.	11°C.	22 C.		12 C.	12 C.	11 C.	11°C.	11°C.

I. Granite. Rockport.
II. Aplite (mean). Bass Rocks.
III. Paisanite. Magnolia.
IV. Granite. Quincy. (Blue Hills.)
V. Keratophyr. Marblehead Neck.
VI. Rhyolite. Marblehead Neck.
VII. Quartz-syenite-porphyry. Squam Light.
VIII. Nordmarkite. Wolf Hill.
IX. Enclosure in Granite. Rockport.
X. Akerite. Gloucester.
XI. Sölvsbergite. Andrew's Point.
XII. Pulaskite. Salem Neck.
XIII. Pulaskite. Salem Neck.
XIV. Sölvsbergite. Coney Island.
XV. Tinguaite. Gale's Point. (Eakle.)
XVI. Foyaite. Great Haste Island.
XVII. Foyaite. Salem Neck.
XVIII. Tinguaite. Pickard's Point.
XIX. Diorite. Marblehead.
XX. Diabase. Rockport.
XXI. Essexite. Salem Neck.
XXII. "Camptonite." Salem Neck.
XXIII. Hornblende Gabbro. Salem Neck.
XXIV. Gabbro. Nahant.

TABLE II.

	Ia	IIa	IIIa	IVa	Va	VIa	VIIa	VIIIa	IXa	Xa	XIa	XIIa
SiO_2	1.294	1.286	1.275	1.232	1.190	1.177	1.148	1.139	1.123	1.110	1.071	1.062
Al_2O_3	.117	.120	.117	.120	.145	.150	.145	.163	.148	.148	.156	.179
Fe_2O_3	.003	.001	.007	.018	.011	.011	.004	.006	.008	.007	.018	.013
FeO	.012	.014	.022	.022	.010	.014	.064	.045	.066	.061	.044	.035
MgO	....	.002	....	.001	.014	.013	.009	.011	.001	.009	.001	.002
CaO	.005	.006	.002	.006	.002	.022	.031	.033	.010	.039	.015	.021
Na_2O	.061	.075	.065	.075	.077	.084	.062	.064	.071	.065	.117	.103
K_2O	.053	.048	.053	.049	.055	.038	.053	.056	.065	.058	.054	.066
$\frac{Na_2O}{K_2O}$	1.15	1.56	1.23	1.53	1.40	2.21	1.17	1.14	1.09	1.12	2.17	1.71
$\frac{FeO}{Fe_2O_3}$	4.00	14.00	3.14	1.22	0.91	1.28	16.00	7.50	8.25	8.71	2.44	2.69
$\frac{Na_2O+K_2O}{SiO_2}$	.088	.096	.092	.101	.111	.104	.100	.105	.121	.111	.156	.159
$\frac{Na_2O}{SiO_2}$	.047	.059	.051	.061	.065	.071	.054	.057	.063	.059	.110	.097

TABLE II.—*Continued.*

	XIIIa	XIVa	XVa	XVIa	XVIIa	XVIIIa	XIXa	XXa	XXIa	XXIIa	XXIIIa	XXIVa
SiO_2	1.052	1.018	1.001	0.989	0.980	0.946	0.864	0.785	0.783	0.777	0.766	0.729
Al_2O_3	.181	.183	.196	.221	.222	.203	.167	.142	.176	.172	.186	.198
Fe_2O_3	.018	.013	.027	.012	.010	.022	.012	.021	.016	.011	.023	.027
FeO	.014	.043	.014	.019	.014	.008	.120	.163	.105	.145	.136	.097
MgO	.004	.011	.005	.004	.005	.003	.122	.151	.080	.194	.117	.098
CaO	.018	.023	.016	.008	.013	.007	.153	.172	.140	.190	.164	.196
Na_2O	.117	.158	.123	.129	.155	.185	.056	.042	.102	.053	.061	.039
K_2O	.056	.064	.034	.043	.052	.031	.019	.012	.029	.008	.023	.015
$\frac{Na_2O}{K_2O}$	2.09	2.47	3.62	3.00	2.98	5.97	2.95	3.50	3.64	6.63	2.65	2.60
$\frac{FeO}{Fe_2O_3}$	0.78	3.31	0.52	1.58	1.40	0.37	10.00	7.74	6.57	13.19	5.67	3.96
$\frac{Na_2O+K_2O}{SiO_2}$	.164	.218	.157	.174	.211	.228	.086	.069	.166	.078	.112	.074
$\frac{Na_2O}{SiO_2}$	.111	.155	.123	.130	.157	.195	.065	.053	.130	.068	.080	.053

A PECULIAR DEVONIAN DEPOSIT IN NORTHEASTERN ILLINOIS

The village of Elmhurst is in the eastern edge of DuPage county, Illinois, on the Chicago and Northwestern Railway, fifteen miles west of the Wells Street Station in Chicago. On the north side of the railway track, about one mile west of the station, are the Elmhurst quarries. The rock quarried, which is the buff or bluish Niagara dolomite of northeastern Illinois and Wisconsin, has been excavated to a depth of about thirty feet.

At this locality the limestone is much fractured by two sets of gentle folds whose axes have a general north-west south-east and north-east south-west direction, joint cracks being well developed. Some of these cracks are several inches in width, and are in general filled with a black or blue clay. At one point, in the south-east face of the quarry, about eighteen feet below the glaciated surface of the rock, one of these joints is somewhat enlarged to form a narrow triangular opening about six inches in width at the base and about sixteen inches in height. This opening, instead of being filled with clay, as are all the other larger joints in the quarry, is filled with a breccia composed of angular fragments of the adjacent limestone, imbedded in a dark brown arenaceous matrix. This matrix is abundantly fossiliferous, containing immense numbers of fish teeth, and a smaller number of *Lingula* shells and other brachiopods, which indicate its Devonian age.

The situation of this most peculiar occurrence of Devonian fossils, deeply buried in the Niagara limestone, is shown in the accompanying illustrations. Figure 1 is a near view, showing the Devonian material filling the triangular opening to the left of the hammer. Figure 2 was taken from a greater distance, in order to show the position of the opening in the face of the

quarry about eighteen feet below the surface. The species of fossils recognized are as follows:

Fish teeth.
Ptyctodus calceolus N and W.
Diplodus priscus Eastman n. sp.
Diplodus striatus Eastman n. sp.

Brachiopods.
Lingula ligea H.?
Orbiculoidea newberryi H.?
Ambocoelia umbonata Con.

The most abundant species is *Ptyctodus calceolus*, whose tritors are present literally by the hundreds. This species is characteristic of the middle and upper Devonian faunas of the inte-

FIG. 1.

rior of North America. It has been recorded[1] from Canada, Milwaukee, Wis., western Illinois, Missouri, Iowa, and Manitoba. The Elmhurst specimens are generally smaller than those usually found in Iowa and other localities, but there seems to be no essential difference in form. The remaining fish teeth are two new

FIG. 2.

species of the genus *Diplodus* which have been described by Dr. C. R. Eastman.

Among the brachiopods, the one identified as *Lingula ligea* is the most abundant. It was originally described from the Hamilton in New York, but it also occurs in the Upper Devonian of the same state and has been recorded from the Devonian in

[1] Iowa Geol. Surv., 1898, Vol. VII, p. 114; Am. Nat., 1898, Vol. XXXII, p. 476.

Nevada. *Ambocoelia umbonata*, a single individual of which has been observed, is a common Hamilton species in New York, although a variety of the same species also occurs in the Upper Devonian. *Orbiculoidea newberryi*, also represented by a single observed specimen, has been recognized only in the Waverly series of Ohio, near the base of the Carboniferous.

The presence of *Ptyctodus* is certainly indicative of the Devonian age of the fauna, but *Diplodus* has previously been recognized only in Carboniferous strata, and the presence of two species of this genus with the Waverly species of *Orbiculoidea* would seem to indicate a very late Devonian age.

The presence of a fauna of this age in such a situation, is of extreme interest. The nearest point where Devonian strata form the surface rock is probably in northwestern Indiana, but that region is so heavily drift covered, and has been so little studied, that the exact distance from Elmhurst to the nearest Devonian strata in that direction cannot be determined with accuracy. Furthermore, the Devonian strata known in northern Indiana, are the black shales, and do not contain a fauna with *Ptyctodus*. The nearest actual outcrop of Devonian is at Milwaukee, Wis., eighty miles north of Elmhurst; and the nearest outcrop to the west is near Rock Island, Ill., one hundred and thirty miles away. At both of these localities *Ptyctodus calceolus* occurs, but the strata are believed to be somewhat older than the material from Elmhurst.

The presence of this Upper Devonian fauna at Elmhurst, buried as it is deep down in the Niagara limestone, indicates with certainty that during the greater part of Devonian time, the region now known as northern Illinois was above sea level. It was part of what was probably a large land surface, stretching from the Wisconsin land on the north to the Ozark land of Missouri on the south. The waters which collected upon this land surface in part percolated through the underlying rock strata and by solution increased the size of many joint cracks. At a later period, near the close of the Devonian, when the sea again occupied the region, sand was sifted down into these open joints, and with

it the teeth of fishes which inhabited the sea thereabout. It is perhaps possible that the opening which has in recent time been uncovered at Elmhurst, was during this late Devonian time large enough for the entrance of some of these fishes, and that they sought this opening for shelter, much as fishes at the present time enter similar openings.

The manner of communication between this opening and the surface is not clearly shown in the field, but arenaceous material

FIG. 3.

with fragments of fish teeth is seen clinging to the quarry face to the left of and above the opening. This material may be rather indistinctly seen in Fig. 1, being represented by the dark blotches upon the lighter colored rock in the position indicated. This rock face is one side of a joint whose opposite side has been removed, through which there may have been communication between the buried opening and the sea bottom above. The

Devonian material is not continuous for any great distance back from the quarry face, as will be seen in Fig. 3, this figure being a view taken nearly at right angles to that shown in Fig. 1, after the rock to the right of the opening against which the hammer leans in Fig. 1, has been removed. The Devonian material in the figure is the darker rock above and to the right of the hat, the line of demarcation between it and the limestone above being sharply defined; it is seen to thin out rapidly back from the quarry face.

At the base of the triangular opening, between the two beds of limestone that come in contact at that point, the Devonian material extends both to the right and to the left for several feet, forming a bed an inch or two in thickness between the two limestone beds. This bed has every appearance of having been deposited upon the lower limestone bed before the upper one was laid down, but in reality it was deposited at a much later date in a cavity which existed there near the close of Devonian time.

The sort of unconformity presented by this occurrence of Devonian sediments deeply buried in the Niagara limestone is peculiar. No description of any similar occurrence has been observed in the literature, and it may be designated by the name subterranean unconformity.

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DESCRIPTIONS OF NEW SPECIES OF DIPLODUS TEETH FROM THE DEVONIAN OF NORTHEASTERN ILLINOIS

Isolated tricuspid teeth with a minute median denticle, similar to those of the Carboniferous and Permian genus *Pleuracanthus*, are provisionally grouped under the name of *Diplodus*, and it has been customary to distinguish the so-called Diplodont and Cladodont types of Elasmobranch dentition according to the relative sizes of the median and lateral cusps. But since the discovery of *Chlamydoselache* in recent seas and the remarkable *Pleuropterygii* from the Cleveland Shale (Upper Devonian), it appears that the above types of dentition were common to several groups of primitive sharks, thus vitiating all generalizations based on the distribution of detached teeth. That species founded on such variable and fragmentary remains can have only a provisional value, pending the discovery of other parts of the skeleton, is further emphasized in the case of some Pleuracanth fishes, which have several forms of "Diplodus" teeth occurring in different parts of one and the same mouth.

As will be pointed out in the following, there are forms of *Phoebodus* teeth intermediate between *Diplodus* and *Cladodus*. This is interesting on account of the close parallelism displayed by teeth adapted for piercing among more or less widely separated groups, but as for throwing light on the interrelationships of these "genera" is wholly without significance. The earliest and most primitive forms of piercing teeth are typified by *Protodus* and *Doliodus* from the Lower Devonian of Campbellton, New Brunswick. *Cladodus* is first met with in the Corniferous limestone of Ohio, and the two new *Diplodus* species described below are the oldest known representatives of that genus. Mr. Stuart Weller, who discovered the material and kindly invited its description, regards the horizon as Uppermost Devonian. The locality is near Elmhurst, Illinois.

Diplodus priscus sp. nov. (Pl. VII, Figs. 1, 2)

Teeth minute; the two principal cusps of dental crown divergent and slightly inclined backward, robust, conical, round in section, without lateral carinae; coronal surface marked with relatively few, prominent, slightly curved striae extending from the base nearly to the extremities on the anterior face, but shorter and usually fainter on the posterior face. Median denticle slender, sometimes much reduced, or in one specimen apparently wanting altogether. Anterior border of root slightly produced downward; lower surface concave, elliptical in outline; posterior button present.

About a dozen examples (chiefly fragmentary) of this species were obtained by Mr. Weller, the largest of which has a total height of 8 mm. One fragment, consisting of the root only, has an elliptical, concave base, with axes measuring 5 mm and 7 mm; a similar but smaller root has axes of only 2 mm and 3 mm respectively. Each of the cones shown in Fig. 2 has eight vertical striae on the anterior face, but if any were present on the posterior face, they occurred higher up than on the part preserved. The length of the median denticle is conjectural, as the tip is missing from all specimens. The intermediate space is occupied by a groove in the tooth shown in Fig. 2, and to all appearances no denticle was present here. This, of course, must be looked upon as an exceptional variation.

Diplodus striatus sp. nov. (Pl. VII, Figs. 3, 4)

Of this species only a few fragments were obtained by Mr. Weller, the largest and most perfect being shown in the accompanying figures. It attains apparently about twice the size of the preceding form, and is readily distinguished by its finer striation, shallower root, and somewhat compressed section of its principal cones. The striae on the anterior face all curve uniformly in a spiral direction (Fig. 4, left-hand figure), but on the posterior face the tendency is to curve outward on either side of the median line to the lateral margin of the cones, where they terminate, exactly as in some species of *Cladodus* (*e. g.*, *C. striatatus* Ag.). This condition is partially indicated in the right-hand illustration of Fig. 4, but other specimens show it more distinctly. One or two fragmentary cones have the striae less

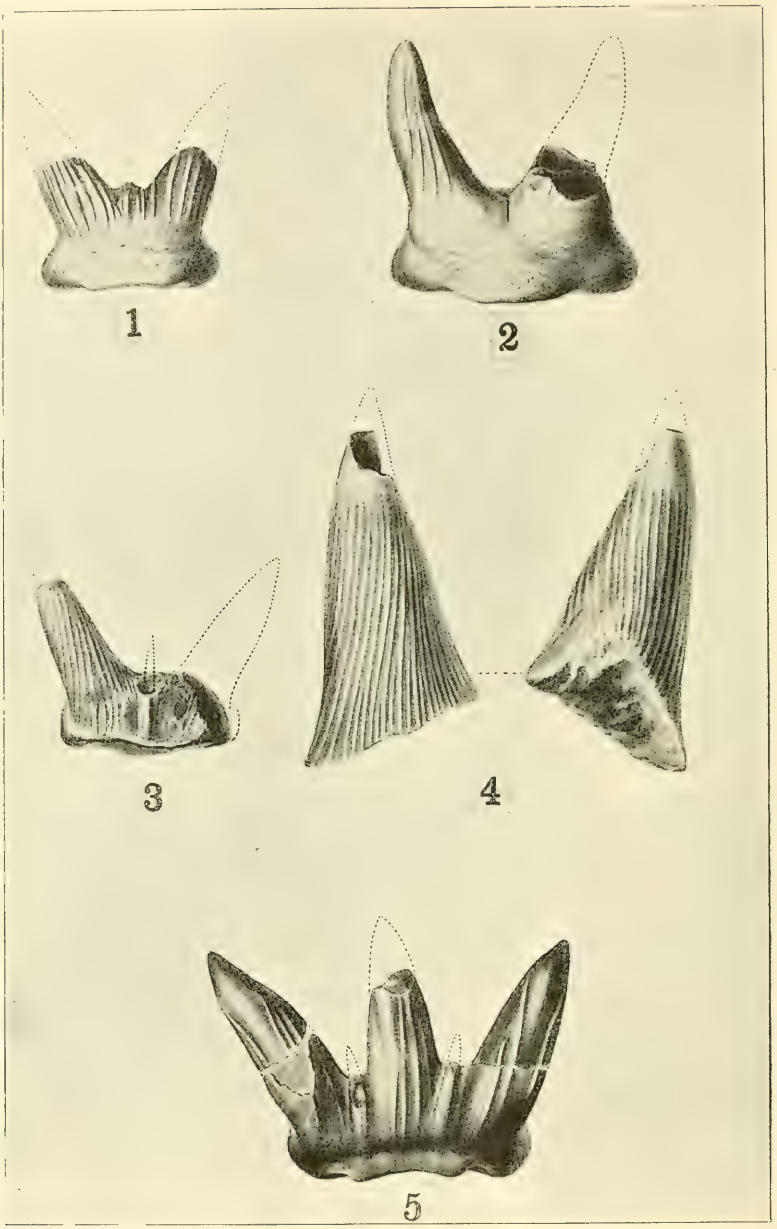
prominent and less numerous on the posterior face, and near the base they may become obsolete altogether. None of the specimens show the full length of the median denticle, but it was apparently long and slender. Further material will be required before the characters of this species can be adequately defined.

Phoebodus politus Newberry (Pl. VII, Fig. 5)

The two new species of *Diplodus* described above differ from most Pleuracanth teeth in an important character which they share in common with Cladodont dentition, and that is the striation of the coronal surface. The concave under surface of the root, peculiar projection of the front margin shown in Figs. 1, 2, and 5, together with the posterior "button," are features quite as characteristic of *Phoebodus* as of the two species of *Diplodus* just considered. As already stated, the form of teeth exhibited by *Phoebodus* is intermediate between *Cladodus* and *Diplodus*. Starting with the latter genus, the transition to *Phoebodus* is accomplished by imagining the median denticle to increase in size until it equals the lateral cones. Further increment in size of the median cone, or reduction of the lateral cusps, which amounts to the same thing, transforms the tooth into *Cladodus*. It is noteworthy that in *Cladodus*, when several lateral denticles are present, the outermost are almost invariably the strongest, and the smaller ones would thus correspond to the intermediate denticles of *Phoebodus*.

Phoebodus politus and other Devonian species have the intermediate denticles well developed, as shown in Fig. 5, but in an unpublished[1] species discovered by Professor W. C. Knight in the Permian of Nebraska, and also in the Triassic *P. brodiei*, only the three principal cones are present. While the coronal surface is striated in the earlier species of *Phoebodus*, it later becomes smooth, and the same observation holds true of *Diplodus*. All three genera under consideration appear to have had teeth

[1] The original specimen is listed as "*Diplodus* sp. nov." in Professor Knight's article on The Nebraska Permian in the last number of this JOURNAL (pp. 372–374).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complicated in one way or another in the beginning, eventually becoming more simplified. But, although mutual resemblances and even intergradations exist, these all seem to be due to parallelism of adaptive modifications.

C. R. EASTMAN.

MUSEUM OF COMPARATIVE ZOÖLOGY,
Cambridge, Mass.

EXPLANATIONS OF FIGURES.

FIG. 1, 2. *Diplodus priscus* sp. nov. Anterior face.

FIG. 3. *Diplodus striatus* sp. nov. Anterior face.

FIG. 4. *Diplodus striatus* sp. nov. Anterior and posterior views of a large detached cone, apparently belonging to same species as Fig. 3. Originals of Figs. 1–4 from Upper Devonian, near Elmhurst, Ill.

FIG. 5. *Phoebodus politus* Newb. Anterior face. Cleveland Shale, Lorain county, Ohio. Original in Museum of Comparative Zoölogy, Cambridge, Mass.

All figures enlarged five times the natural size.

DIPTERUS IN THE AMERICAN MIDDLE DEVONIAN

LAST summer, while engaged in field work in Muscatine county, Iowa, the writer found a tooth of *Dipterus calvini* Eastman in the Cedar Valley limestone at Fairport, on the north bank of the Mississippi. It belonged to a horizon some eight or ten feet below the highest ledges of this limestone exposed

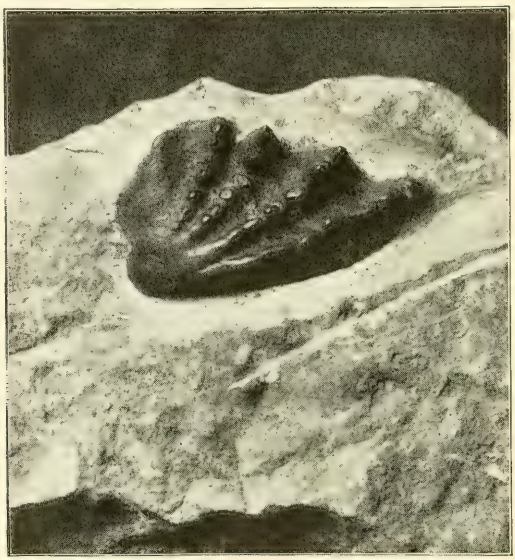

FIG. 1.—A tooth of *Dipterus*, sp., from the base of the Cedar Valley limestone, near Buffalo, Iowa, natural size.

in the county. A few feet below these ledges there are seen two black layers of porous bituminous rock.[1]

This horizon is characterized by a fauna more rich in lamellibranchs and gasteropods than that of the ledges below. There is also to be found one or two species of *Cranaena* and a form of *Strophaeodonta demissa* with coarser costae than usual. This

[1] These ledges have been called the Straparollus ledges. See Iowa Geol. Surv., Vol. IX, Pl. VI.

fauna comes in above the ledges from which Owen collected fossils that he referred to the Chemung ("*Spirifer euruteines*," etc.).

Lately I have found another somewhat more strongly tuberculated tooth of *Dipterus*, (see Fig. 1) near Buffalo, Iowa, at a level about 25 feet lower down in the same limestone. The ledge from which this tooth came, contains *Striatopora rugosa* and *Megistocrinus latus*. It is directly under the ledges in which Spirifer parryanus first appears. It has yielded teeth of *Ptychtodus* and fragments of *Dinichthys pustulosus*. Some coral-bearing ledges, full of fossils, lie four or five feet above it.[2] The ledge belongs to the Hamilton as described by Worthen in Rock Island county, Illinois, on the opposite side of the Mississippi, and comes in some fifteen or twenty feet above its base.

While this fish is reported from the Lower Devonian in Europe and Great Britain, it has not before this, I believe, been observed as low down as the Middle Devonian in America, to which age American geologists have referred the fauna of this limestone.

J. A. Udden.

[2] Megistocrinus bed. Iowa Geol. Surv., Vol. IX, Pl. VI.

STUDIES FOR STUDENTS

A CENTURY OF PROGRESS IN PALEONTOLOGY

THE presence of fossils in the rocks was observed by the ancient priests of Egypt, by the Brahmans of India, and by many other ancient peoples. In some cases the bones of gigantic mammals, such as the mammoth and mastodon, were observed, and, being considered as human bones, they gave origin to many of the beliefs in the existence of races of giants. The Greeks and Romans also observed fossil shells, bones, and plants, and some of their philosophers speculated as to their origin, although little or no progress was made in their study. Some of these men believed that the shells found preserved in strata far inland were really the shells of once living animals, while others, with Theophrastus, "supposed them to be produced by a certain plastic virtue latent in our earth."

It was not until the early part of the sixteenth century that geologic phenomena began to attract the attention of the Christian nations. At that period an animated controversy sprang up in Italy concerning the true nature and origin of marine shells and other fossils found abundantly in the strata of the peninsula. In the year 1517 extensive excavations were made in Verona, which brought to light a multitude of curious petrifactions, and furnished matter for speculation to different authors. Among these was Fracastoro, who declared "that fossil shells had all belonged to living animals, which had formerly lived and multiplied where their exuviæ are now found." He exposed the absurdity of having recourse to the plastic force of Theophrastus, which had power to fashion stones into organic forms, and also demonstrated the futility of attributing the situation of the shells in question to the Mosaic deluge, a theory that was obstinately defended by some. Fracastoro, however, had but few companions in his clear and philosophical views, and for nearly

three centuries two simple and preliminary questions were vigorously discussed—(1) whether fossil remains ever belonged to living creatures, and (2) whether, if this be admitted, all the phenomena could not be explained by the deluge of Noah.

Throughout all this long controversy regarding the nature and origin of fossils, little was done in the way of description of fossil forms; but with the reformation of the system of nomenclature by the introduction of the binomial system, instituted by Linnæus during the latter half of the eighteenth century, the way was opened for a more accurate description of fossils than had been practicable previously. Linnæus himself described and named some species of Silurian fossils from Sweden, among which may be mentioned the well known and widely distributed *Atrypa reticularis* and *Halysites catenulatus*, although the genera in which these species are now placed are of later date.

The real scientific study of fossils may be said to have begun with about the opening of the present century. William Smith (1790), in England, had recognized the value of the fossil contents of the rocks in tracing the strata over extended areas, but he did not devote his time to the description and naming of the fossils which he found. At about this same time rich stores of beautifully preserved fossils were discovered in the immediate neighborhood of Paris. The labors of Cuvier and Brougniart upon the vertebrates, and of Lamarck upon the fossil shells of this area, constitute some of the earliest really scientific investigations of fossil organisms. In fact, it may be said that Cuvier laid the foundation of the science of paleontology, when in 1797 he called attention to the fact that elephant bones discovered in the Paris basin were different from the bones of living species, and thus drew a distinction between living and extinct animals as implying present and past groups of living organisms.

Many of the works on paleontology published in the early part of the present century exhibited little or no attempt at classification of the materials described. The classic work of James Sowerby, entitled "Mineral Conchology," which was published in seven volumes, the first of which bears the date 1812

on the title-page, and the sixth 1829, a work in which very many of the species of British fossils were originally described, may be taken as a type of this group of works. In the arrangement of the matter included in these volumes no attempt is made at classification, either zoölogically or according to the geologic horizons in which the fossils were found. It is simply a paleontologic scrapbook, as it were, of descriptions and illustrations of fossil species. One plate, with its accompanying descriptions, may be devoted to Tertiary gastropods, the next to Paleozoic brachiopods, a third to Cretaceous ammonites, a fourth to Tertiary gastropods again, and so on, the total number of plates in the whole work being 648.

Following the early period in which there was to a great extent an absence of classification, the classification of fossils gradually developed along two distinct lines. On the one hand, with the increase of knowledge and with the progress in taxonomy of living organisms, the zoölogical classification of fossils made rapid strides, and many orders, families and genera founded wholly upon fossil forms were established, and were fitted into the scheme of classification of all organisms, making it far more complete than it could ever have been made from the study of living organisms alone. On the other hand, there grew up a classification of fossils into faunas, so that a whole series of extinct faunas, from the earliest Paleozoic time to the recent, were recognized. It also gradually came to be established that the sequence in time of extinct faunas, in their larger characteristics, was the same for all parts of the world where fossils were found.

For many years these two systems of classification of fossils went forward hand in hand, but with the development of the science the two paths along which progress was being made became more and more divergent, until at the present time the two divisions of the subject have become fully differentiated.

It is of interest to trace the differentiation of these two lines of progress in the life work of such a paleontologist as the late James Hall, whose career extended over more than half a century.

In the earlier volumes of the paleontology of New York, the faunal classification of fossils is predominant. Many new species and genera are described as members of the faunas under discussion, there being no elaborate investigations into the natural taxonomic grouping of organisms. In volume four of the work we begin to see the deviation of the line of investigation toward the biologic side, the faunal grouping being made subordinate to the taxonomic. This same subordination is seen in volumes five, six, and seven, while in volume eight we find the faunal classification entirely displaced, and the whole volume devoted to the treatment of the genera of Paleozoic brachiopods. We have, therefore, in this series of volumes an exhibition of the development of the science as illustrated by the life work of one man, from the faunal classification in 1847, through the mixed faunal and biologic, to the purely biologic classification in 1894.

This differentiation of the science, which has become nearly accomplished at the present time, is well exhibited in the character of the paleontologic monographs which have been published during the past decade or less. On the one hand such works as Wachsmuth and Springer's monograph of the "Crinoidea Camerata," a work which is strictly biologic in its treatment of this extinct order, is an illustration of one division of the subject, and on the other hand may be mentioned Walcott's "Fauna of the Olenellus Zone," where the biologic treatment of the fossils is made entirely subordinate to their faunal associations.

While these two branches of paleontologic science have been differentiating, the older method of investigation has by no means disappeared, and during this whole century of progress there have been appearing constantly contributions to paleontology of the "scrapbook" order. Among the more recent of these made upon a large scale may be mentioned the series of bulletins which have been issued from the Illinois State Museum of Natural History during the past decade. In these contributions some hundreds of species have been described, belonging to various classes and orders of organisms and from various geologic horizons, but they have contributed little or nothing either to the

taxonomy of the subject or to the faunal relationships of the fossils described. Such work, however, is valuable even today in so far as it is accurately done, because it relieves the investigator in the more special lines of research from a vast amount of labor. Every species of fossil must have a name as a sort of handle by which it may be manipulated, but with the more special workers in the subject, the description of species and the giving of names is but a means to an end, the discovery of new species not being the ultimate result sought after.

The biologic division of paleontology consists of the study of the structure and organization of individuals, of their ontogenetic development, of the relationship of species to species and of genera to genera, and of their phylogeny, all with the ultimate end of establishing as nearly as possible a natural classification of all organisms. A large proportion of all the work being done today among fossil vertebrates comes into this category. Among the invertebrates much work of a high order is also being accomplished. The recent contributions by Beecher upon the structure, ontogeny, and classification of trilobites and of brachiopods may be mentioned, also the contributions by Hyatt and others upon the cephalopods.

The faunal study of fossils is intimately connected with geology, in fact no history of the earth, from the period beginning with Cambrian time, can be made complete when the life history is excluded, and for this reason this faunal study of fossils is coming to be called paleontologic geology. Instead of taking a single species or any taxonomic group as the unit of study, as is done by the biologist, organic societies, those organisms which lived in a single locality under similar environment during a limited period of time, are the subjects of investigation. The fossil societies or faunas are dissected into their various elements, their relation to the environment in which they existed are studied, their relations to neighboring societies or faunas, both in time and space, and their migrations are the subjects of investigation. The study is a history of organisms in its broadest sense, and it is just as truly an historical study as is the study of human his-

tory. In fact many parallels may be drawn between this history of faunas and the history of the races of men.

Those organisms which are preserved in the sedimentary rocks, and among which our historical investigations may be carried on, are to a large extent the marine organisms which inhabited the shallow seas which have existed in past time upon the continental platforms, both on the borders and in the interiors of the continents. The life of the dry land, that of the fresh waters, and the aërial life, cannot have been preserved except under exceptional conditions. The ancient life of the abysmal depths of the oceans is unknown to us because of the entire, or at least approximate, absence of abysmal sedimentary deposits upon the continents.

Among the earlier geologists of the century, whose individual observations were limited to comparatively small geographic areas, at a time when the literature of geology and paleontology was but limited, the notion grew up that identity of fossil species and identity of age of the strata containing the fossils always went together. But gradually, with the increasing knowledge of living marine organisms, especially of their geographic distribution into more or less distinct provinces limited by physical conditions such as temperature, depth, ocean currents, purity of water, etc., and with the broadening knowledge of fossils themselves, when it came to be realized that the same organisms did not live everywhere at the same time in the past, but that, as now, there were also during all geologic time distinct zoölogic provinces inhabited by distinct faunas, and, furthermore, that these provinces were constantly changing their geographic boundaries, then the task of accurate or even approximate correlation of strata over any great distances from their fossil contents seemed to become almost hopeless. Indeed, so hopeless did the task seem to some that in 1862, in his presidential address before the Geological Society of London, Huxley[1] said: "For anything that geology or paleontology are able to show to the contrary, a Devonian fauna and flora in the British

[1] Q. J. G. S., Vol. XVIII, p. 46.

Islands may have been contemporaneous with Silurian life in North America and with a Carboniferous fauna and flora in Africa. Geographical provinces and zones may have been as distinctly marked in the Palæozoic epoch as at present, and those seemingly sudden appearances of new genera and species, which we ascribe to new creation, may be simply results of migration."

It was doubtless due to this seemingly more or less chaotic condition of the geographic distribution and the geologic range of fossils, that the majority of the students of extinct life during the latter part of the century have turned their attention to the biologic rather than to the geologic problems involved; but these very investigations which the biologists have made have materially assisted the paleontologic geologist in his researches. The biologic paleontologist may, and often does, carry on his investigations and make valuable contributions with little or no knowledge of the geologic phases of the science save the more or less dogmatic assertions of text-books. But the paleontologic geologist must of necessity follow closely the results of his biologic brother, though his own investigations may be something entirely different. In fact, the perfection of the taxonomy of fossils is to the paleontologic geologist but one of the means to an end, and not the ultimate end sought. The two divisions of the science may be compared with the ancient and the modern methods in the study of human history. The biologic division may be compared with the older method of historical study, in which the lives of a few conspicuous characters monopolized the whole study. On the other hand, the investigations in paleontologic geology may be compared with the modern scientific study of history, in which the evolution of society is made most prominent, the conspicuous characters being considered as the results of social conditions rather than as their causes.

At the present time it is believed by most, if not all, geologists and paleontologists that the great geologic systems represent practically the same time-periods throughout the world. It is also believed by many that the limits of the recognized

geologic periods, in so far as they are really natural divisions of geologic time,[1] are practically contemporaneous. It is also believed that about three divisions in each period may be usually detected with much certainty throughout the world, although the constitution of the faunas may vary to a considerable degree.

It becomes the task of the paleontologic geologist to investigate the fossil faunas, the organic societies of past time. Through a study of the geographic distribution of species and genera and their relationships to preceding and succeeding forms, the approximate limit of the zoölogic provinces of past time are determined, and from these data approximate restorations of the ancient geography are made. From a study of the changing physical conditions and the changing faunas are determined the migrations which we now know to have taken place and which Huxley suggested as a cause of sudden changes of fossil faunas.

Among fossil faunas as a whole there are two conspicuous types, (1) the cosmopolitan faunas and (2) the provincial faunas. At different periods of the earth's history these two types of faunas have been dominant. During Silurian time, for instance, there seems to have been in existence a great cosmopolitan, shallow-water, marine fauna, which is represented in America, in Europe, in Australia, and New Zealand, and probably will be discovered also in the other continents. The conditions for the development of such a fauna seem to have been the presence of widespread, shallow seas upon the continental platforms, epi-continental seas, as they have recently been called.[2] With broad seas of this sort around the borders of the continents, and extending into the interior by means of great tongues or lobes, and with conditions approximating base-levels upon the land, there would be a great limestone forming epoch, and with the probable atmospheric conditions of such an epoch[3] the tempera-

[1] See "The Ulterior Basis of Time Divisions and the Classification of Geological History," by T. C. CHAMBERLIN, JOUR. GEOL., Vol. VI, p. 449.

[2] JOUR. GEOL., Vol. VI, p. 602.

[3] JOUR. GEOL., Vol. VI, p. 609.

ture conditions upon the earth would be far more nearly equable than they are today, so that the same species could live both in the tropics and in the polar regions, as the distribution of the fossils indicates to have been the case. Under such conditions the shallow-water marine organisms would have the most favorable opportunity for intercommunication with all parts of the world, and there would be developed just such a cosmopolitan fauna as we know existed in Silurian time.

The Devonian period gives us a good illustration of the provincial type of faunas. During this period the shallow-water marine faunas exhibit a great diversity in various parts of the world. The Devonian faunas in New York, or even in southern Illinois, have less in common with those of Iowa, than have the Silurian faunas of the interior of North America with those of Europe or even with those of Australia. The Devonian faunas of Europe are also different from the American, and, furthermore, they differ among themselves. In South America and other parts of the earth there are still other types of Devonian life. The evidence afforded by the distribution of species and genera indicates without a doubt that the provincial development of faunas was one of the most conspicuous characteristics of the period. This type of development was, of course, brought about by the greater or less isolation of great shallow-water tracts in different parts of the world, in each of which the evolution of the life progressed along its own peculiar lines, molded by the particular environmental conditions which obtained in each tract or province.[1] Because of the more or less complete isolation of these various provinces, and the absence of shallow-water paths along which intercommunication between distant parts of the earth was possible, the development of a cosmopolitan fauna such as existed in Silurian time was out of the question.

In addition to the provincial development of the Devonian faunas, the life history of the period is complicated in a still further degree by reason of the continuous changes in the

[1] See "A Systematic Source of Evolution of Provincial Faunas," by T. C. Chamberlin, JOUR. GEOL., Vol. VII, p. 597.

geographic limits of the provinces themselves. The major development of the several great Devonian provinces was, in all probability, in shallow seas upon the borders of the continents, and the more important changes in their areal distribution was probably due to the cutting away of barriers formed by the more or less elevated rim of the continents, and the extension of lobes of the sea into the interior, so forming interior epicontinental seas. It is in the sediments of these interior epicontinental seas that the greater portion of all our Paleozoic life records are preserved. The borders of the continents are the chief regions of disturbance during periods of dynamic activity, so that the records of the life in the normal border provinces of such a period as the Devonian are to a great extent destroyed.

If we were able to possess ourselves of sufficient data in regard to the border provinces, it is probable that no sharp life breaks would be found, but in the interior epicontinental seas, the case is very different. By the slow cutting away by erosion of the barrier rim, or by the local sinking of the land, communication is established successively between the interior seas, and first one and then another of the great border provinces, and there are successive incursions of very different faunas, which make their appearance in the interior very suddenly, although their evolution has been in progress in some border province during a long lapse of time. As an illustration of such a sudden appearance of a fauna into an interior epicontinental sea, the fauna of the Corniferous in eastern North America may be mentioned. This fauna with its large number and variety of corals, its great number of cephalopods including the first goniatite, and, most of all, the host of armored fishes, appears with comparative suddenness, probably from the north through Hudson Bay, and includes many organisms which could not possibly have been derived from the preceding Devonian faunas, the Oriskany and Helderberg. The evolution of this fauna had probably been in progress during all the preceeding time since the Silurian in its more or less isolated province, but its appearance in the

interior epicontinental sea of Devonian time in eastern North America was relatively sudden.

Such a sudden appearance, in a series of sedimentary rocks, of a new fossil fauna, with apparently no genetic predecessors in the immediate region, may be compared with the sudden appearance in North America during the sixteenth century of the advanced culture and civilization of Europe among the savage tribes which had occupied the continent previous to that time. Although the appearance in America of the white man with his advanced culture was sudden, and his influence spread so rapidly that it soon drove into practical extinction the preëxisting and less advanced culture of the Indian, it was really the culmination of a long and gradual development, in Europe, of the art of building and sailing ships. In a similar way the sudden appearance of a new fossil fauna in a series of sedimentary rocks may be but the culmination of some physical change which has been in progress during an extended period of time. The submergance or the erosion of a land mass may be slow, and may continue through a long lapse of time, but the culmination of the phenomenon will be when the land passes below sea level, thus removing a barrier and allowing the immigration of a marine fauna into a region previously occupied by a very different assemblage of organisms. The conflict following such an immigration may be compared with the conflict between the Indian and the European cultures in America.

The resulting fauna from any such incursion and mingling within an interior sea, as has been described above, will of course be different from either of the original faunas. The Corniferous fauna in eastern North America, in addition to that element which came in from the outside, contains also an element which may be traced directly back to the preceding Oriskany or Helderberg faunas which had inhabited the same region. When the German tribes made their incursions into the Roman Empire, bringing in a new culture, the old Roman civilization and culture was not entirely destroyed, but there was built up a new civilization and a new culture, differing from either the Roman or the

German, which included elements from each. In the same way a resultant fauna, formed by the mingling of two or more faunas, will contain elements from each which can be detected by a careful study and dissection of the entire assemblage of organisms.

In general, the species in any fossil fauna fall into one of two categories: (1) indigenous evolution species, or those whose ancestors have lived in the same region and whose evolution has there taken place, and (2) immigration species whose ancestors have lived in some other geologic province and whose sudden appearance in the fauna under consideration is due to an immigration from the outside. It is the work of the paleontologic geologist to investigate each species of the fauna he may be studying, to determine in which category each belongs, and in the case of the immigration species to determine in what part of the world or in what geologic province its previous evolution has taken place, and what are the probable paths of migration.

In the historical study of fossil faunas it is interesting and suggestive to draw parallels with the history of human races. Until comparatively recent times there has been a remarkable provincial development of the races of men. Among the more primitive peoples a range of mountains or a great river was a sufficient barrier to prevent migration, because, as in the case of the provincial faunas, they had not means at hand for intercommunication between the separated provinces. But there has been a gradual development among the human races, of means of communication, first by beasts of burden and later by mechanical devices, until today, through the agency of the great ocean steamers, the transcontinental railways, and the telegraph, no corner of the inhabitable earth can be said to be isolated. With the increased facilities for intercommunication, there is being developed a great cosmopolitan human race, which will in time inhabit the whole earth, just as in far-away Silurian time there was developed, by reason of the widespread shallow waters upon the continents, a cosmopolitan fauna which reached from North America to Australia.

The questions involved in this faunal history of the earth are

complicated, but the fossils imbedded in the rocks are the data, and these are far more indisputable than are the data upon which ancient human history is being built. A recent writer gives the following definition of ancient history:[1] "A confused jumble of traditions, distorted to suit special pleaders; then rejumbled, and mixed, and confused, and redistorted according to the design of each new writer—the story of noble actions of big-minded men recast in the crucible of petty intellects, untrained in public life and unfit to grasp even the commonplace—the story of petty actions seized upon by enthusiasts and exalted into a nobility which would have been beyond the recognition of the original actors—all sorts of stories attempted to be told by weak, incapable men without purpose, or by unconscientious men or wilful liars with a purpose—obscure acts twisted into curious shapes in the brains of industrious writers—truth taken by well-meaning men and so changed by ignorance and lack of comprehension and unfitness to judge that it loses all semblance of its original self and becomes a misshapen, irrecognizable, utterly twisted and contorted thing, without much more than a vestige of fact upon which it is supposed to be based. This is ancient history." If the human historian is able to build up a story of the human race from such data, how much more certainly will the paleontologic geologist, by diligent study and investigation of his absolutely indisputable data, be able to build up a creditable history of the life of the earth since Cambrian time.

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[1] JOHN BRISBEN WALKER, in The Cosmopolitan, March 1899, p. 476.

EDITORIAL

"ABOUT a Reform in Nomenclature" is the title of a communication in the issue of *Science* for July 28, by A. L. Herrera, of the National Museum of Mexico. Preliminary to a specific suggestion, attention is called to the almost insupportable burden into which the nomenclature of the natural sciences has grown and to the imminent need of reform. The meaninglessness of many current names is a serious hindrance to the dissemination of science. "The language of science is more difficult than science itself."

The need of reform can scarcely be urged too strenuously, and every voice raised in its interest is welcome. There is, nevertheless, occasion for great circumspection in the adoption of substitutes for the present names. It is possible, perhaps, to make matters even worse than they now are. There is some ground for the suspicion that this might be true of the proposed reform, the chief features of which are as follows:

The generic names of animals to end in *us*, those of plants in *a*, and those of minerals in *i;* minerals, to have generic names formed from abbreviations of the names of their chemical constituents, as *sulphurzinci*, *sphalerita;* the generic names of plants to be preceded by abbreviations of the family names, as *Rosaspiræa limbata;* with a similar device for the names of animals.

One of the most serious faults of the present binomial system is its instability, due to changes of reference of species to genera. This is especially true in paleontology where the original data were imperfect and new discoveries are being constantly made, and are sure to continue to be made for a long time to come. Now, to add the name of the family in the form of an abbreviation-prefix would introduce another variable factor, one, perhaps, even more subject to change than the generic

reference. Furthermore, the addition of the prefix would make the already cumbrous nomenclature still more ungainly. Reform should move in the direction of simplicity and fixity as well as significance.

In naming minerals there is no occasion for the introduction of the bungling binomial system. There would be an obvious advantage in deriving the names of minerals from those of their chemical constituents, as suggested, but if this is done a uniform terminal syllable is a pedantic superfluity. *Sulfozinc* would sufficiently show that the subject was not a plant or an animal, without the terminal *i*. So also the *sphalerita* becomes nearly needless and quite incongruous, as it belongs to the meaningless system which it is proposed to eliminate. In place of it a syllable to express the form of crystallization would carry out the fundamental idea.

The most hopeful suggestion yet made for mineralogical nomenclature proposes that the names shall consist simply of a combination of syllables which shall indicate the crystalline form and the essential chemical constituents, since these are the characterizing elements. The main difficulty of such a system lies in securing brevity and euphony. It would be easy enough to improve upon the present uncouthness in the main, but not to reach good phonic combinations in all cases. Much could be done, however, by leaving out all useless lumber and all superfluous tailpieces, by reducing the abbreviations to their lowest terms, and by giving them the best possible combining forms. If this required that some liberties be taken in forming the abbreviations it would be merely introducing into language that regard for economy and utility which characterizes progress in all the live arts. T. C. C.

Reviews

RECENT BOOKS ON PHYSIOGRAPHY

Rivers of North America. A Reading Lesson for Students of Geography and Geology. By Israel C. Russell. Pp. 326. G. P. Putnam's Sons, 1898.

Earth Sculpture, or the Origin of Land-Forms. By James Geikie. Pp. 397. G. P. Putnam's Sons, 1898.

Physical Geography. By William Morris Davis, assisted by William Henry Snyder. Pp. 428. Ginn & Company, 1899

These three volumes deserve the careful attention of teachers and students of physical geography and geology, not only in secondary schools, but in colleges as well. Some of them should also appeal to a large class of readers who are lovers of nature, though their work is not in educational lines.

Professor Russell's book is well described by its explanatory title, "A Reading Lesson for Students in Geography and Geology." In this volume the author has presented in readable form the leading processes and principles involved in the history of rivers. In addition, he has introduced, as the title suggests, much descriptive matter concerning the rivers of our own continent. The matter is not too technical for the high school student who is serious in his work, and will be read with profit by college students who have rarely had a physiographic topic so well presented on the printed page.

The scope of the book is in a measure indicated by the headings of the various chapters: The Disintegration and Decay of Rocks; Laws Governing Streams; Influence of Inequalities in the Hardness of Rocks on Riverside Scenery; Material carried in Suspension and in Solution; Stream Deposits; Stream Terraces; Stream Development; Some of the Characteristics of American Rivers; The Life History of a River.

In treating of these various topics the author has made no attempt to be exhaustive, for the book has been prepared, not for the professional geographer, but for the general student who has had too little

readable matter at his command. The advanced student may wish that the book were fuller and more explicit at some points, while others into whose hands it will fall, will wish it more elementary. Such infelicities are not to be avoided, and it would have been difficult, on the whole, to have made a better selection of material. Important topics have not been omitted, and unimportant and irrelevant ones have not been introduced. Throughout the book the modern nomenclature of rivers has been used, and on this account those who have not followed the progress of geographic science during the last ten years will find it to their advantage to read the book in course, rather than otherwise.

The volume has some effective illustrations, though their number is too small (17 plates and 23 figures in text), which add to its otherwise attractive appearance.

Professor Geikie's volume deals with the processes involved in the development of topography, and with the results which these processes have effected. The first chapter is devoted to a general discussion of the agents of denudation. The principles and processes of denudation are then studied with immediate reference to land masses affected by various types of structure. The topographic forms developed in regions of horizontal strata at various stages in the progress of denudation and under various conditions are first considered. The same principles and processes are then applied to regions where the strata are inclined, and the topographic results under these conditions are described and illustrated, as in the preceding case. Passing from the more simple to the more complex, the effects of denudation in regions of folded and highly disturbed strata are next set forth, and numerous cuts are introduced illustrative of the more complex topographic forms which result from denudation where the stratigraphy is complicated.

The consideration of the topographic forms developed by denudation in regions possessed of various types of stratigraphy is followed by a consideration of the topographic effects of faults, and of volcanic and other types of igneous action. Unfortunately the last of these topics is less adequately illustrated than most of the preceding. The lack of illustrations here may be less serious than it would have been elsewhere, since illustrations of the topographic effects of volcanic action are among the most common in our geographies. Nevertheless, the absence of abundant illustrations seems to us a defect.

Following the discussion of these topics, a chapter is devoted to the topographic features which depend for their existence upon the character of the rock rather than upon the position of its beds. The topographic effects of structure other than stratification and the results of the varying composition of rock are considered.

To the topographic effects of glaciation two chapters are given, and while the text is clear, no virtue which it possesses can compensate for the entire absence of cuts illustrative of the points described. Nowhere are illustrations more needed, and in no field are they more easily obtained. The topographic effects of eolian action, involving a brief consideration of dunes and of rock sculpture effected by the wind, and of the surface effects of underground water, are next considered. In the case of the last topic, illustrations are again altogether wanting.

A chapter is given to the discussion of basins (depressions without outlets), and illustrations showing the real nature of basins are introduced which will tend to correct the prevalent erroneous notions concerning the shape of these topographic features. The topography of coast lines is briefly discussed, and too meagerly illustrated. It is with regret that the lack of illustrations is repeatedly referred to, but in a book of this sort, which deals almost exclusively with the forms of the surface, the lack of illustrations is especially serious.

The volume closes with a classification of land forms. It is to be especially noted that the classification comes in the right place, after (and not before) a consideration of the processes of earth sculpture and their results, and therefore when the reader is for the first time in a position to appreciate the force and the meaning of the classification. This is a point which the writers of books intended to be educational would do well to note. Many of our text-books are lumbered with elaborate synoptical classifications preceding the discussion of the things which are classified. When the classification in such positions is reached by the student he has no comprehension of its meaning, and too often does not refer to it after the chapter is read.

In spite of the one notable defect which has been referred to, Professor Geikie's book is to be heartily commended to students and teachers of geography.

Professor Davis's book differs from the others in being a text-book. The author has followed traditional lines to the extent of including in the volume a consideration of the atmosphere and the ocean as well

as the land; but he has departed from traditional lines in according to the former topics but brief treatment, while the larger part of the book is devoted to the geography of the land. The author is understood to believe that the subject of meteorology should be separated from that of physical geography (of the land) and pursued as a distinct subject in the secondary schools. Whatever may be said of the desirability of this change, it is not likely to come about at present, and for a good while to come such attention as is given to meteorology in the secondary schools is likely to be in connection with physical geography. If this be true, the consideration of the atmosphere in this volume seems to us too brief; on the other hand, the selection of material is excellent, and in so brief a space it would have been difficult to present a more satisfactory outline of the subject. The inadequacy of the treatment, however, appears to be recognized by the author himself, who indicates that it should be supplemented by "local observations and by the construction and study of weather maps." Brief appendices give some suggestions for this observational and constructional work, but the average teacher in the secondary school will find these suggestions still more inadequate than the text they supplement. Much fuller directions will need to be given to teachers in the secondary schools before the majority of them can direct the sort of work which Professor Davis rightly advises.

The consideration of the ocean is likewise exceedingly brief (34 pages). Both the selection of material and its presentation are excellent, but the small amount of space devoted to the subject is insufficient to give even all the important points with which the student of the subject, even in an elementary way, should be acquainted.

As already noted, the larger part of the book is devoted to the consideration of the land surfaces, and it is not too much to say that the geography of the land is presented in an essentially new light. Here traditional lines are not at all followed, and no one whose knowledge of the subject has been derived from other text-books can read this without learning much concerning the subject and concerning the methods of presenting it. The descriptive element enters more largely into this volume than into most recent books on physical geography. Topographic types are illustrated by descriptive references to specific areas, many of which have not been well known to professional geographers. In other words, concrete illustrations of general types abound, and they are drawn from wide sources and are definitely pictured.

Plains, plateaus, and mountains as topographic types are considered in order, and many illustrations of the various phases of these general types, drawn from all parts of the world, are introduced. The treatment of coastal plains is especially happy. The question might be raised whether the idea of the coastal plain is not carried rather far when, under the heading of "Ancient Coastal Plains," areas very distant from the sea, and which now have nothing to suggest their "coastal" relations, are discussed. Thus "the ancient coastal plains" of Wisconsin seem to us a little remote for consideration in an elementary physical geography. The teacher who is a geologist as well as a geographer will know how to treat this subject; but it seems to us likely that the text will fail to convey the right notion of these "ancient coastal plains," which are no longer coastal plains, to many pupils if not to many teachers.

The important chapters on Rivers and Valleys is excellent, and should prove effective with classes if they have the guidance of skillful teachers.

A significant chapter of the volume is entitled Climatic Control of Land Forms. Here are considered such topics as the effect of climate on streams and their work; salt lakes; the life of arid regions; glaciers and ice-sheets and their work. It must be confessed that the fashioning of the land surface by the continental ice-sheet of North America seems doubtfully placed in a chapter with the above title, for while glaciation was of course a result of the climate of the time, the topography which the ice fashioned is as really the work of the ice as the topography developed by rivers is their work; and it can hardly be said that glaciers and ice-sheets are more directly controlled by climate than rivers are. The discussion of glacial topography under the caption of Climatic Control of Land Forms, therefore, seems to us not the happiest possible arrangement. The volume closes with an excellent chapter on Shore Lines. Numerous brief appendices are added which will be helpful to the teacher of the subject.

Throughout the volume emphasis is laid on the effects of geography on human development, and references to historical incidents, as influenced by topography, are frequent. This is a phase of the subject which is most welcome.

In a book which is so thoroughly good it may seem gratuitous to mention defects, but there is one which seems to us somewhat serious. There is an occasional lapse into an obscure style, resulting from the

introduction of ideas for which adquate preparation has not been made, or from the two brief exposition of complex phenomena. The result is that the pupil, if not his teacher, will sometimes be staggered. From actual experience with a group of teachers, it has been found that a large proportion of them do not catch the idea of a *cuesta* (p. 133), and it is not easy to see what good purpose the introduction of the term serves, *for the pupils who will use this volume.* The defect referred to above will, it is to be feared, interfere with the usefulness of this very excellent book.

The volume is abundantly illustrated (261 figures and 10 plates) and every illustration is to the point. Half-tones have been excluded, and engravings put in their place. There can be no question but that in most cases the engravings are much more effective than reproductions directly from photographs, for the non-essential features are omitted, and the essential features brought into prominence. We have seen no text-book on this subject in which the illustrations so uniformly illustrate the exact points which they were meant to illustrate, and in such a way that their meaning cannot be mistaken.

The three volumes mentioned above put new and rich resources into the hands of teachers and students of physiography, and should result in great improvement in the teaching of the subject.

R. D. S.

Transactions of the Kansas Academy of Sciences, 1897–8. Vol. XVI.

This volume of 320 pages indicates a laudable degree of activity in various scientific lines. The presidental address by Dr. S. W. Williston on "Science in Education" is an admirable exposition of the existing status and current tendencies of education in liberal and professional lines and contains excellent suggestions relative to desirable changes in which science shall be a larger factor. The papers in geology and paleontology are six in number as follows: Physiography of Southeastern Kansas, by George I. Adams; *Fusulina cylindrica* Shell Structure, by Alva J. Smith; New Developments in the Mentor Beds, by A. W. Jones; Fossil Turtle Cast from the Dakota Epoch, by C. S. Parmenter: Deep Well at Madison, Kan., by F. W. Bushong; Correlation of the Coal Measures of Kansas and Nebraska, by J. W. Beede.

T. C. C.

Iowa Geological Survey, Annual Report, 1898, Vol. IX. By SAMUEL CALVIN, State Geologist; H. F. BAIN, Assistant State Geologist.

Statistics of Mineral Production. By S. W. BEYER; *Geology of Carroll County*, H. F. BAIN; *Geology of Humboldt County*, T H. MCBRIDE; *Geology of Story County*, S. W. BEYER; *Geology of Muscatine County*, J. A. UDDEN; *Geology of Scott County*, W. H. NORTON; *Artesian Wells of the Belle Plaine Area*, H. R. MOSNAT. Thirteen plates, 56 figures, 14 maps.

This volume of the reports of the Iowa State Geological Survey serves to corroborate the high opinion already established among the geologists of the United States of the work of this organization. The record of the Iowa survey has been one of uninterrupted excellence in both the theoretical and the economic phases of its work. The list of the corps engaged in the work of 1898 is of itself sufficient to invite inspection of the report.

Each of the county reports gives a systematic exposition of the physiographic and economic features of the geologic field under consideration, each being emphasized as the peculiar characteristics of the district demand. To many of the reports is appended a discussion of the forestry of the areas studied.

In the geology of Carroll county the physiography is of exceptional interest, since the tract is bisected diagonally by the edge of the Wisconsin drift sheet. Consequently the northeastern and southwestern parts of the county display topographic features in admirable contrast as the result of these relations. The Middle Coon River follows this drift margin in a general way, receiving numerous tributaries with secondary and tertiary branches from the area of Kansan drift westward, while from the Wisconsin drift there is only one important tributary and that without branches. The erasure of post-Kansan drainage by the Wisconsin invasion is illustrated by a number of examples. The Coon River, flowing across the northeast part of the county has constructed a makeshift course from "bits of old captured valleys, and new trenches which it has cut for itself."

The stratigraphy of Carroll county includes an exposure of a Carboniferous limestone, probably of the Des Moines series. The Cretaceous is represented by several exposures of the Dakota sandstones and

conglomerates. Some of these conglomerates include silicified Niagara and Devonian fossils as part of the clastic materials. A few Cretaceous fossils have been identified. Undoubted chalk rock of the Niobrara, containing abundant *Inoceramus labiatus*, is exposed in one locality in association with the Dakota sandstone.

The Pleistocene deposits are considered in detail. A new development from the field investigation is the demonstration that much of the extra-Wisconsin drift, hitherto provisionally correlated with the Iowan, belongs to an anomalous phase of the Kansan, which shows many peculiarities, near the border of the Wisconsin, due either to some protecting influence during the period of post-Kansan erosion, or to some subsequent modification referable to the presence of the loess and the proximity of the Wisconsin drift. The loess is called Iowan in age and lies beneath the Wisconsin, except at some places where a thin mantle of it covers the edge of the latter, evidently as a recent wind deposit. The loess of this region is not of sufficient depth to have developed its own peculiar type of topography.

The coal prospect for Carroll county is an exceedingly uncertain problem and, in Dr. Bain's opinion, is to be solved only by the drill, and that only at large expense, chiefly because of the great depth of the drift. Moreover, the great distance from the known outcrops of coal make it possible that the productive measures may have thinned out altogether in Carroll county. The other mineral resources of the county are inconsiderable. The water supply is entirely sufficient. The area includes several artesian wells.

The report for Carroll county is fairly representative of the method and character of the work done in the other counties and only special details of the other papers demand consideration. Mr. T. H. McBride, in the report upon Humboldt county, identifies the Kinderhook and Saint Louis of the Mississippian series and the Des Moines of the Coal Measures. The latter is covered by the glacial series, of which the pre-Kansan, Aftonian, Kansan, Buchanan and Wisconsin are recognized.

The Wisconsin sheet is merely a thin veneer, conforming to the previously established Kansan-Buchanan topography. This is worthy of note in the light of other observations on the relations of recent drift sheets to underlying unindurated formations. The somewhat paradoxical inference is suggested that the ice sheet was normally less competent to disturb the surface of a deep formation of loose materials than the surface of an exposed indurated rock. A gravel formation,

as it was being overridden, became the basal part of the ice and exhausted to a degree its transporting capacity, forming the effective load of the natural stagnation zone at the base of the ice. Over a rock surface, on the other hand, the ice may have possessed its maximum of transporting and abrading power.

A unique detail in the drainage of Humboldt county is the practice, reported of draining kettle-hole lakes in certain districts by sinking wells through impervious layers to a porous stratum. The method appears to be effective and economical, though its sanitary bearing upon the drinking water of the region may be worthy of consideration.

A notable feature of Mr. Beyer's report on Story county, also of Professor Udden's on Muscatine county, is the determination of deformations. The gentle flexures, of which the Skunk River anticline is a type, are suggestive when considered with similar structures which have been reported at many points in the exposures of different formations across the upper Mississippi basin. The reiterated recognition of such structure suggests that the phenomena of crustal shortening have been restricted by no means to the mountain belts of the coastal regions but that these gentler flexures, affecting such immense areas, may have been, in the aggregate, an equally notable factor in the adjustment of the external masses of the earth to internal changes.

Mr. Beyer gives an excellent report on the stratigraphy, including many valuable well records. The discussion of the development of the Skunk River system is an instructive physiographic study. The course of the pre-Wisconsin channel, the transference of much of the Skunk River drainage area to the Des Moines system by the Wisconsin invasion, the post-glacial struggle of the stream toward readjustment, form the substance of a finely developed discussion. Remains of the Mammoth are reported by Mr. Beyer from an excavation four or five feet below the surface of the Wisconsin drift. Coal, clay and building stones are the economic products of Story county.

The report on Muscatine county by Professor Udden is characterized by carefully derived conclusions and is rendered thoroughly readable by the excellent style of presentation, and enjoyable by the variety of new and sharply observed phenomena. The stratigraphy of the county includes the Gower stage of the Niagara, Wapsipinicon and Cedar Valley stages of the Hamilton, Sweetland Creek beds of the Upper Devonian, Kinderhook group of the Mississippian and the Des Moines stage of the Coal Measures. This article contains an exhaustive discussion

of the drift with many close, but distinctly drawn, discriminations. The following Pleistocene formations are recognized : anteglacial silts, pre-Kansan, Aftonian, Kansan and Illinoian. The anteglacial silt is a new division. It is explained as having been formed by water and wind ahead of the invading pre-Kansan ice-sheet. If that be its origin, it might properly belong with the pre-Kansan drift and the division would appear unnecessary. If every aqueous deposit of the drift should receive a special name, the clarifying effects of analysis would soon be lost in confusion. The economic products of Muscatine county include coal, though in unprofitable amount, small quantities of gas, building stones and clay.

The geology of Scott county, by Professor W. H. Norton, contains much fresh information. The passages in the paper dealing with the history of the drainage and with the stratigraphy are of special value. Touching the former, this region is particularly interesting because of its location at the southern limits of the driftless area and the consequent complexity of the drift phenomena arising from the mutual interference of the ice lobes at this place.

The report on the artesian wells of the Belle Plaine area by H. R. Mosnat gives a thorough exposition of the geology of the water-bearing formation, the amount of the flow and the source of the water. The computations rising from the study of flow and supply develop many facts which simplify to a great degree the conception of the combination of conditions appropriate to the formation of artesian wells. A most significant passage is that discussing the rate of movement of the underground water through materials of different texture. It is estimated that nineteen years would be required for the water of the aquifer to move in a direct line from Vining to Ladora along the major axis of the artesian area. Hence, the writer concludes, the great exhaustion of the water body brought about at Vining by the remarkable flow of the great Jumbo well when it was opened, will not affect the flow at Ladora before the year 1905. He also shows the limited extent of surface actually necessary to supply the water for the aquifer and the adequacy of the rainfall to produce the supply without any recourse to the extravagant superstitions which have made this artesian area "the eighth wonder of the world" in the minds of the inhabitants of the region. The discussion is closed with a paragraph on the uses of the water, which largely relegates the wells to the category of interesting

geological phenomena whose practical and economic value is doubtful or, at any rate, decidedly limited.

This volume is carefully printed and amply illustrated by expressive and well selected photographs, sections and sketch maps.

J. W. Finch.

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THE

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THE OZARKIAN AND ITS SIGNIFICANCE IN THEORETICAL GEOLOGY.

I. THE OZARKIAN.

In 1886 I published a paper entitled "A Post-Tertiary Elevation of the Sierra Nevada, as shown by the River-beds."[1] Again in 1891 I published a paper on "The Mutual Relations of Land Elevation and Ice Accumulation during the Quaternary Period."[2] The following paper may be regarded as a continuation of the lines of thought suggested by the two preceding.

By continued reflection on the enormous changes that occurred in the western part of the continent at the end of the Tertiary, I have been led to recognize the existence of an epoch of long duration and of great importance immediately preceding the time of the invasion of the ice sheet. On account of its great importance this epoch certainly deserves a distinctive name. For want of a better, I adopt that of the "Ozarkian," given it by Hershey.

History of the name.—The epoch was first recognized by Hilgard and more distinctly by McGee, as the post-Lafayette uplift,

[1] Am. Jour. Sci., Vol. XXXII, p. 167, 1886.

[2] Bull. Geol. Soc. Am. Vol. II, p. 329.

shown by extensive erosion of the Lafayette gravels all over the southern states. But a distinctive name was first given it by Hershey,[1] who called it Ozarkian in commemoration of its work in the formation of the remarkable gorges of the region of the Ozark Mountains. He, however, fully recognized its importance as a time of general uplift and erosion, but regarded it as only an episode comparable with the Kansan or Iowan episodes of the Glacial epoch. The name was adopted, though somewhat reluctantly, by McGee (Sci. III, 796, 1896), and its importance more fully recognized,[2] but he regards it as belonging to the Pliocene and not the Quaternary. This point we shall discuss later. A little later (Am. Geol. XVII, 389, 1896) Upham also adopts the name, and, like Hershey, refers it to the early Quaternary, but advances it to a *primary* division of that period comparable with the Glacial. But even yet, it seems to me, its full importance is scarcely recognized unless it be by McGee, and its true significance entirely overlooked. Indeed both its importance and its significance are brought out in strong relief only by the study of its phenomena in the western part of the continent and especially in California.

If with Upham we divide the Quaternary period into three epochs, the Ozarkian, the Glacial, and the Champlain, then the Ozarkian was by far the longest, in fact, longer than both the others put together. Or again, if the Quaternary be divided into two epochs, the Ozarkian and the Glacial, the Champlain being merged into the Glacial, as is commonly done by European geologists, then of the two, the Ozarkian is by far — perhaps by many times — the longer. In many ways the Ozarkian is strongly contrasted with the other epochs of the Quaternary. If, for example, we adopt the division into three epochs, these are characterized each in its peculiar way; the first, by elevation; the second, by ice accumulation; the third, by depression; the first, by immense erosion; the second, by glaciation and drift deposit; the third, by stratified deposits in seas and lakes.

[1] Science III, 620, 1896.

[2] "The reference of the Ozarkian to the Pleistocene would multiply by many times the commonly recognized duration of that period." McGee, Sci. III, 796, 1896.

The Ozarkian has heretofore attracted little attention, because until very recently geological history was supposed to be recorded only in stratified rocks and their contained fossils; but this being a period of continental elevation and enlargement, it has left no strata exposed to view. Geological history was at that time recorded only by erosive work. So far as stratified rocks and fossils are concerned, this is a period of lost record—it is a *lost interval.*

I said that the real importance and significance of this epoch is best seen on the western part of the continent. I must justify this assertion by a comparison of the phenomena in different parts of the continent.

1. *The eastern part.*—In the eastern part of the continent, the work of erosion of this time is seen in the so-called old river-beds deeply underlying the present beds and extending beyond their limits on each side, and especially continuing beyond the limits of the present continent, as submerged channels trenching the submerged continental shelf, notching deeply its margin and opening out into the abyssal waters of the true oceanic basin. It is shown also not only in the deep gorges of the Ozark region, not only in the deep and widespread erosion of the Lafayette gravels in the south, but also in the highly emphasized topography underlying the drift all over the glaciated region of the north. By means of the submerged channels the amount of vertical elevation of the eastern portion of the continent has been estimated as certainly not less than 3000–5000 feet and may have been much greater. Similar evidences of elevation are found on the Pacific coast and also on the coasts of Europe and of Africa. We have every reason to believe that it was a time of almost universal continental elevation and enlargement.

Heretofore these old rivers of the east have been referred, like those of the west, to the Tertiary times and called Tertiary river-beds; although it is admitted that they were occupied and deepened by the ice of the Glacial times. The Tertiary erosion was supposed to have graded insensibly and continuously into that of the Glacial, but the greater part was attributed to the

Tertiary; and the post-Tertiary erosion was supposed to be wholly Glacial. According to my view, on the contrary, the post-Tertiary erosion was by far the greater and was pre-Glacial in time, *i. e.*, Ozarkian.

In the eastern portion of the continent, therefore, the Ozarkian grades into the Tertiary, but is well marked off from the present by the depression and sedimentation of the Champlain.

2. *The mid-continental or plateau region.*—In the plateau region, on the contrary, the Ozarkian work is sharply marked off from the Tertiary, but grades insensibly into that of the present.

It is well known that the plateau region has been rising ever since the end of the Cretaceous—that from being the lowest part of the interior continental basin, it has become the highest part of the continental arch. The amount of elevation during this time has been at least 20,000 feet, about 12,000 of which has been carried away by erosion, leaving still 8000 feet of general elevation. Of this enormous general erosion, the largest part—shown by the receded and still receding cliffs—probably belongs to the Miocene. The canyon-cutting is certainly post-Miocene. The outer canyon (of the Grand Canyon) ten to fifteen miles wide and 3000 feet deep, belongs to the Pliocene; while the inner gorge, 3000 feet deep but very narrow, belongs to the post-Pliocene, *i. e.*, to the Ozarkian and the present.

I said the Tertiary work is sharply marked off from the Ozarkian but the Ozarkian grades insensibly into present. The evidence of this is given by Dutton, as follows:

Between the Pliocene work of the formation of the outer canyon, and the subsequent work—Ozarkian to present—the cutting of the inner gorge, there was an interval of rest marked by a wide shelf between the two. The rising and the down-cutting was continuous during the Pliocene until finally the river reached its base level of erosion and rested from further downward cutting and commenced to sweep from side to side widening its channel, until the canyon walls were nearly ten miles apart. Then began the Ozarkian rise and the beginning of the

cutting of the inner gorge, which has continued to the present time. The elevation during the Tertiary was regional, the elevation which commenced with the Ozarkian was continental or even more widespread. In the east there was a sharp demarcation of the Ozarkian from the present erosion by the Champlain depression and sedimentation; which depression, as I suppose, was determined by the weight of the ice sheet. But in the plateau region there was no ice sheet — it did not extend so far — and therefore there was no depression and therefore no interruption of the erosion to the present time; for the rising is still progressing. The whole series of phenomena in this region may be well explained by a local rise continuous from the end of the Cretaceous till now, except that it was interrupted at the end of the Pliocene by the Lafayette depression of McGee and afterwards greatly enhanced by the general continental elevation of the Ozarkian.

3. *Sierra region.* — But it is in the Sierra region alone that we find the Ozarkian erosion-work sharply marked off both from the Tertiary on the one hand and from the present on the other. It is here therefore that the distinctive Ozarkian work can be best studied.[1]

Brief history of the Sierra.—The Sierra Nevada, as is well known, was formed at the end of the Jurassic by lateral pressure and strata-folding in the usual way. What kind of a mountain it was at that time, how high, and what its configuration we know not; for the continuous erosion of the Cretaceous and Tertiary times had nearly swept it clean away. The cycle of its mountain life had reached its last stages. By continuous erosion it had been reduced to a peneplain, with its wide-sweeping curves of broad shallow channels and low-rounded divides. The rivers had reached their base levels and rested. This was the work of the Cretaceous and Tertiary.

Then came the post-Tertiary rejuvenation of the mountain

[1] As the term *Ozarkian* had already been used by Broadhead for a Lower Silurian series in the Ozark region (Am. Geol., XI, p. 260, 1893) there may be an admissibility of its use in this connection. If so, I would propose the name *Sierran* as far more appropriate.

life,[1] by the formation of a fissure on the eastern slope, the heaving of the whole mountain block on its eastern side with a great eastern fault-scarp,; the transference of the crest to the extreme margin with great increase of the western slope and consequent revival of the erosive energy of the rivers. Coincident with this in middle California there was a great outpouring of lava which ran in streams down the western slope, filling up the old river beds, and displacing the rivers. The displaced rivers, with recently and fiercely aroused energy, immediately commenced cutting new channels, which are now 3000 to 6000 feet deep, and far below the old; so that these latter are left with their lava-covered gravels high up on the present divides This was the work of the Ozarkian. This intensely interesting geological story has been so often told that we only recall here its outlines in order to apply them to the case in hand.

In southern California, beyond the limits of the lava flows this post-Tertiary elevation and revival of erosive energy was fully as great, or even greater than in middle California; but the rivers were not displaced, and therefore they continued to cut in the same places, but to far deeper levels; so that the margins of the wide old river beds with their gravels are left hung up high on the sides of the present canyons.[2] The distinction, however, between the wide shallow tertiary troughs and the deep narrow post-Tertiary canyons is equally sharp here.

We have spoken thus far only of the deep canyons which trench the western slope as being of post-Tertiary origin; but the same is true also of the whole scenery of the high Sierra. It all belongs to the post-Tertiary, and its bold, rugged, savage grandeur is due to its extreme recency. The wildness of youth has not been yet tempered and mellowed by age.

It is evident then that the Ozarkian is here sharply marked off from the Tertiary. How is it in regard to its relation to the present? In the lower parts of the canyons the Ozarkian grades insensibly into the present, for the rivers are still cutting. But

[1] Am. Jour. Sci., Vol. XXXII, 167, 1886.

[2] Am. Jour. Sci., Vol. XXXII, 174, 1886.

in their upper parts the two are separated by the glacier erosion. The upper canyons were occupied by glaciers, and the comparison of these upper with the lower canyons shows that while their forms were modified, and perhaps their depths somewhat increased, they were not made by this agency. This was mainly the work of the post-Tertiary but pre-Glacial times, *i.e.*, of the Ozarkian. But the glaciation serves to show how much has been done by water since the Glacial, *i. e.*, during the present times; and we find it very insignificant.

In conclusion, no one who sees and reflects upon the prodigious work done in the Sierra since Tertiary times can resist the conviction that even making all due allowance for exceptional energy and rapid work, determined by high slope and also for other causes of rapid work explained in a previous paper,[1] the time necessary must have been enormous — many times as great as any reasonable estimate of the duration of the Glacial epoch.

II. SOME MODIFICATIONS OF MY PREVIOUS VIEWS.

In the article already alluded to, on the "Relation of Land Elevation and Ice Accumulation" I attempted to reconcile the two antagonistic views in regard to the attitude of land during the Glacial epoch. According to some writers the land in high latitude regions was greatly *elevated;* according to others it was on the contrary *depressed.* According to the one, the intense cold and ice accumulation was the direct result of the elevation, and a subsequent depression produced a moderation of the climate and a melting and final disappearance of the ice; according to the other, the ice accumulation was not coincident with the elevation and, therefore, there must have been some other cause for the cold and ice accumulation. In the paper referred to I showed that all the phenomena might be satisfactorily explained by supposing that the elevation was the cause of the cold — the cold the cause of the ice accumulation — the weight of the accumulated ice the cause of the depression — the depression the cause of returning

[1] Origin of Transverse Mountain Valleys, Univ. Chronicle, Vol. I, No. 6, p. 179, 1898.

warmth — the warmth the cause of the melting and retreat of the ice, and finally that the removal of the ice-load was the cause of the re-elevation to the present condition; but — and this is the distinctive feature of my view — that in all these cases *the effects lagged behind the causes*. I showed that this was so in all cases of accumulated effects, but would especially be true in this case. To illustrate these relations I used a diagram which I here pro-

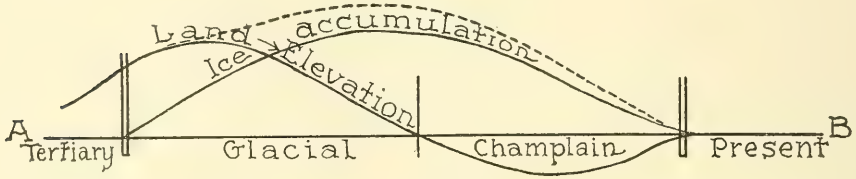

FIG. 1.— Diagram showing the relations of land elevation and ice accumulation during the Quaternary. *AB* — course of time and also the present status of earth crust. The dotted line shows elevation if it had not been interfered with by the ice-load.

duce. The legend will sufficiently explain it. By this view the Quaternary consists of two epochs, the Glacial and the Champlain, of nearly equal lengths. The one characterized by elevation and cold, the other by depression and warmth, but the extreme of ice accumulation lagged behind the extreme of elevation as seen in the figure.

I am more and more convinced that the principle of lagging is a true one and even more important than I at that time supposed. I now believe that I did not at that time make the lagging, especially in the matter of the accumulation of the ice-load, great enough. We must make a distinction in this regard between the intensity of the cold and the thickness of the accumulated ice. The cold probably responded somewhat promptly to the land elevation, but not so the ice accumulation. This was a very slow process and might lag to any degree behind the elevation and the cold. This we now proceed to show.

1. Snowfall depends on cold, but still more upon moisture.

Now there is nothing in the way of supposing — but on the contrary much reason to believe — that the period of great elevation was one of comparative dryness and that the climate became moister in the latter part when the elevation was not so great. This would make the ice accumulation lag behind the elevation and the cold.

2. But again: We must, of course, make a wide distinction between the annual snowfall and the rate of accumulation; for this latter is the result only of the annual *excess* of snowfall over waste by melting and evaporation, and this excess may be to any degree small.

3. As it is, the *thickness* and therefore the *weight* of the snow that we are here concerned with, it must be remembered again that there is still another and much more important source of waste antagonizing local accumulation and therefore increase of thickness, viz., the run-off — not the run-off as water but as ice by glacial motion. After a certain thickness is attained this run-off completely balances the annual excess over waste by evaporation and melting, and prevents, farther increase of thickness. This is the case now in all glacial regions. In the Alps, the Himalayas, etc., there is no indefinite increase of thickness because the run-off by glacial motion completely balances the annual excess. Similarly in Greenland, and the Antarctic continent although there is great excess of snowfall over waste by evaporation and melting, yet there is no increase in the thickness of the ice sheet because the excess is balanced by the run-off of the ice into the sea and the formation there of icebergs which are carried away by oceanic currents.

So also in Glacial times, after a certain thickness of snow had accumulated on any given area — say the Canadian highlands — the farther increase would be prevented, because balanced by the ice-sheet motion in all directions. Any increase of thickness would require not only excess but *increase of excess* and would be extremely slow because always kept in check by the increased run-off.

To sum up: Suppose, then, the highlands about Hudson

Bay to have been the center of elevation, of ice accumulation and of radiating run-off: Suppose farther, that the elevation commenced about the end of the Pliocene and was the cause of the cold. Then considering the previous warmth of the Tertiary times, it is probable that the elevation would go on for a long time and reach a considerable degree before there would be any snowfall at all in this region, and still much longer time before there would be annual excess over waste by evaporation and melting, *i. e.*, before there would be *perpetual snow.* After perpetual snow was reached, under the effect of the ice-sheet motion tending ever to bring about equilibrium, the increase of the thickness of the ice sheet must have been extremely slow. In fact, it is evident that no such thickness as actually occurred could

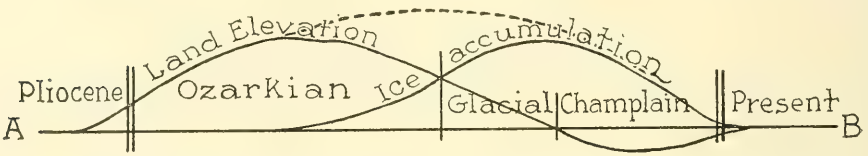

FIG. 2.—Diagram showing supposed relation of land elevation to ice accumulation, as now revised.

have been attained at all, but for the subsidence of the earth-crust under the weight of the ice. The increased thickness was conditioned upon and waited on the subsidence. I believe, therefore, that an increase of one inch per annum would be an extravagant estimate. At this rate it would take 150,000 years to make a thickness of 12,000 feet, which is the estimate of Dana. To this must be added the much greater time before the perpetual snow was formed at all.

Under the light of these estimates and especially of these new views of a long Ozarkian epoch preceding the glacial epoch, I would therefore modify my previous diagram, making the beginning of the ice accumulation much later and making both the Glacial and the Champlain much shorter than before, as shown in the revised diagram, Fig. 2. The greater distinctness of the Ozarkian from the Glacial is shown

III. SIGNIFICANCE OF THE OZARKIAN.

In my papers on *Critical Periods in the History of the Earth*, in 1877 and in 1898[1] I try to show that there are periods of great and widespread changes in the earth's crust, in climate, and in organic forms. These I call "critical periods" and insist that they separate the primary divisions of geological, time, viz., the *eras*. Being periods of great elevation and enlargement of continents, they are to a great extent "lost intervals," *i. e.*, periods in which the usual record of stratified rocks and contained fossils is interrupted. The last of these was the Quaternary. The Ozarkian was largely a lost interval so far as stratified record is concerned.

Great cycles in the evolution of the earth.—Now an era, *i. e.*, the time from one critical period to another, must be regarded as one great cycle of widespread changes; during which, however, there may have been and indeed undoubtedly were, subordinate and more local cycles. Such a great cycle was the Paleozoic, very regular in its course in this country. Such another great cycle was the Mesozoic, but affected in this country with a well marked subordinate division at the end of the Jurassic. Still another such great cycle and again very regular in this country was the Cenozoic, and such another, I am convinced, is even now commencing. I have called it the Psychozoic.

I have supposed these to be cycles in the evolution of the earth. They are, therefore, such in every department alike. They are cycles in the evolution of earth-forms, *constructively*, *i. e.*, by *interior* forces in continental elevation and mountain formation. They are cycles in the evolution of earth-forms, *destructively*, *i. e.*, by *exterior* forces and erosive sculpturing. They are cycles of evolution in climatic conditions. And, finally, as the result of all these, they are also cycles in the evolution of organic forms and their geographical distribution. Most of these various forms of cyclical movement I have discussed in my previous papers, especially that in 1895. These, therefore, I merely

[1] Am. Jour., Vol. XIV, 99, 1877. Bull. Geol. Dept. Univ. Cal., Vol. I, 314, 1895.

mention and pass on. Some, however, I discuss fully now for the first time.

1. *Cycles of constructive forms.*—Of the four great kinds of earth movements treated of in my address as President of Geological Society of America, December 1896,[1] the greatest, viz., that by which are formed oceanic basins and continental arches, being determined by unequal radial contraction in the secular cooling of the earth, which in its turn is the result of an original heterogeneity in the density and especially in the conductivity of different parts of the earth, must have a cycle coëxtensive with the life of the earth itself, and therefore may be left out in this discussion. But superimposed on this greatest, there are other cycles of oscillations of the earth's crust over wide areas—of continental elevation and depression, accompanied with the formation of great mountain ranges. These are the cycles of next importance, and with which we are here concerned; for they determine all other cycles mentioned above, and therefore the occurrence of what I call critical periods. They are demonstrated by the widespread unconformities which occur at these times. Upon these, again, are superimposed still lesser cycles which, however, do not concern us here. I have sufficiently treated of these, both great and small, elsewhere, and therefore pass on.

2. *Cycles of climatic conditions.*—Coincidentally with the changes by continental elevation and depression with their attendant mountain-making, there have undoubtedly been concurrent changes in climatic conditions of many kinds, especially of temperature. These changes were, on the whole, probably gradual throughout the era, but culminate and oscillate in the critical period which closed it and constituted one of its most marked features. The two most conspicuous examples are those which occurred at the end of the Paleozoic and at the end of the Tertiary. The early Paleozoic was eminently an oceanic period. During the whole Paleozoic there was, in this country at least, a gradual elevation and enlargement of the continent,

[1] Bull. Geol. Soc. Am., Vol. VIII, p. 113, 1897.; Sci., Vol. V, p. 321, 1896.

slow at first, but rapidly increasing toward the end and culminating in the formation of the Appalachian chain. Concurrently with this there was, almost certainly, a gradual decrease of temperature rapidly culminating at the end in something approaching, at least, a true glacial epoch in the Permian. Similarly, there was probably, during the Tertiary, a gradual elevation and increase of land and diminution of temperature, culminating somewhat rapidly at its end, in the Ozarkian elevation and the Glacial ice sheet. Similar changes occurred at other critical periods, but less conspicuously.

I have been accustomed, in default of any other and more probable cause, to attribute the increase of cold directly to the increase of elevation, although admitting its possible insufficiency. It is this apparent insufficiency that constitutes the only justification of extra-terrestrial theories of Glacial climate, such as Croll's, etc. Recently Professor Chamberlin has contributed to the JOURNAL OF GEOLOGY[1] some admirable and suggestive speculations on the cause of these cycles of climate and of life. According to him, the continental elevation is not the direct, but mainly the *indirect* cause of cold, by the exhaustion of the supply of CO_2 in the air by continuous rock-decay during these land-periods. This supply is supposed to be restored from the interior of the earth through fissures, etc., produced by the commotions of these times. He, moreover, correlates these changes in elevation and in temperature in a most suggestive way with alternating richness and poverty of life and corresponding alternations of limestones and sandstones. I cannot, of course, dwell on these very suggestive views, but only draw attention to the fact that the cycles of which Professor Chamberlin speaks correspond to the *smaller* or subordinate cycles spoken of on pages 536 and 537, and *not* to the great cycles separated by critical periods and constituting eras. Nevertheless, there is no reason why similar causes acting with greater intensity at long intervals should not determine the greater cycles also.

3. *Cycles of geographic diversity of organic forms and of rates of*

[1] JOUR. GEOL., Vol. VI, pp. 597, 609, 1898.

evolution.— We have already explained in a previous paper[1] how, during the course of a cycle, the geographical diversity of organic forms in isolated regions becomes greater and greater indefinitely as long as isolation continues, until finally synchronic correlation of strata in different regions becomes difficult or impossible. But that during critical periods (and to less degree at other times) there occur wide migrations and mingling of faunas and corresponding obliteration of geographical diversity, only to commence again with new isolations and a new geographical diversity increasing again with time. Thus there are alternations of increase and obliteration of faunal diversity. This idea has an important bearing on the doctrines of synchrony and homotaxy. At the beginning of a great cycle immediately after a critical period, geographical faunas commence, as it were, all abreast; synchrony and homotaxy are now in harmony. As time goes on, the newly mingled but re-isolated faunas develop in different directions and at different rates, become more and more divergent in character, and more and more different in grade of evolution. Synchrony and homotaxy become more and more discordant, until at the end of the cycle it becomes extremely difficult or even impossible to correlate strata of different countries synchronically. Then there comes another critical period of widespread oscillations of crust and readjustment to new conditions of equilibrium with accompanying oscillations of temperature and wide migrations of species and mingling of faunas and floras, hastening the steps of evolution everywhere, but obliterating geographical diversity, and, as it were, evening up again synchrony and homotaxy, only to commence a new cycle by re-isolation.

An attempt is made to roughly represent this process by a diagram (Fig. 3). In this diagram two cycles are represented. In the first, Europe is ahead, and increasingly so as the cycle goes on, and Australia is most lagging. In the second, North America is ahead. In each the divergence between synchrony (the full waving lines) and homotaxy (the horizontal dotted

[1] Bull. Geol. Dept. of Univ. of Cal., Vol. I, p. 314, 1895.

lines) becomes greater and greater until the end of the cycle, when there comes a critical period of wide migrations of species (represented by the horizontal arrows), a mingling of faunas, a fiercer struggle for life, together with the more active operation of other factors of evolution, and a consequent hastening of the steps of evolution everywhere, but especially in the lagging areas, to a more or less even general line. In the second cycle

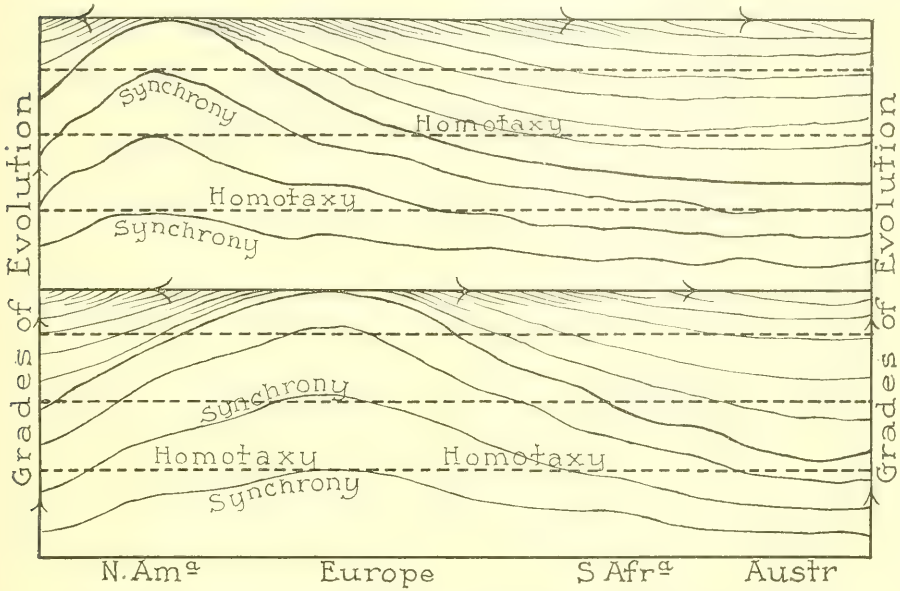

FIG. 3. Diagram showing the general relations of synchrony to homotaxy in geological times. Full lines represent the same time in different places (synchrony). Horizontal dotted lines represent equal stages in evolution (homotaxy).

the same process begins and progresses, except that now America is ahead, and increasingly so until the next crisis; when the synchronic lines are again evened up to parallelism with the homotaxic. If it were not for these occasional evening-ups a general geological history based on organic remains would be impossible.

The whole process may be likened to a long army line marching abreast over a broken country, led by officers, who may be compared to the dominant types. Soon the line

becomes irregular, and more and more so, until it is no longer discernible and all seems confusion. At certain intervals the leaders run along the lines hastening up the laggards until the line is re-formed. But the re-formed line again soon becomes irregular and falls into confusion, and is again re-formed, and so on.

Of course partial and more or less local readjustments of synchrony and homotaxy take place at intermediate times at the end of subordinate cycles. Sometimes in the general readjustment some locality may be left out. This is the case with Australia today. The last wide migrations and minglings of faunas and obliteration of geographical diversity, viz., that during the Quaternary, did not reach Australia, and therefore its fauna is still far behind in the race of evolution.

4. *Cycle of topographic forms by erosion.*—But there is still another cycle, and one with which we are especially concerned here, viz., the *cycle of erosion-forms.* Every critical period is a time of the formation of great mountain ranges, and the crisis is usually named after the mountain range which forms its most conspicuous monument. Thus we have the Appalachian revolution, closing the Paleozoic; the Cordilleran, closing the Mesozoic. The pre-Cambrian crisis might well be called the Laurentian, and the one we are now specially dealing with, viz., the Quaternary or Ozarkian, might well be called the Basin Ranges revolution; for not only the basin ranges, but also the Sierra Nevada, the Coast Ranges of California, and the Mt. St. Elias Range of Alaska were either formed or else rejuvenated at that time.

Thus with every critical period there are new mountains formed and old ones rejuvenated; new lands formed by emergence of sea bottoms and old ones elevated or depressed. Thus new constructional forms are made and a new cycle of destructional or erosive forms inaugurated. These forms pass gradually through the stages so graphically described by Professor W. M. Davis and others, the final result being the so-called *peneplain.* Of course, there are subordinate, intermediate, and more local cycles; and therefore at the end of the great cycle

we may have examples of both old and new topography. But in any case a critical period, being the beginning of a new great cycle, after such a period we have only or mainly new topography. This is the true and conclusive answer to Professor Tarr's objection to Professor Davis' far-reaching deductions from the supposed discovery of the remnants of former peneplains. Professor Tarr objects that if there be any such former peneplains there ought to be peneplains formed now and in the present geological epoch—that the very foundation of geology as an inductive science consists in the use of causes and processes now in operation as the basis of reasoning on phenomena of earlier times. Yes, *causes* and *processes* now in operation, but not *results* and *forms* now existent and produced in the present epoch. Causes and processes are constant, or nearly so, but resulting forms pass through a regular cycle of evolution-changes. Now the *last cycle is just commenced.* We must wait at least a few millions of years before we can expect to find peneplains made out of the recently inaugurated and highly emphasized topographic forms. As a note of warning against hasty generalizations Professor Tarr's paper cannot be too highly commended. We are all too apt to be carried away by a new idea. It is apt to become a fashion of thought for which we are ever seeking confirmation; and in all complex and imperfectly understood questions, what we seek earnestly for we are very apt to find. It is possible, yea, it is probable, that the peneplain idea has been overworked; that many of these ancient peneplains exist only in the fervid imagination of the too ardent geologist. Nevertheless, the principle is a true one and undoubtedly a very fertile one. Geological history has heretofore been based almost wholly on the results of sedimentation. It is time that it should be based also, and equally, on the results of erosion. These results may be more difficult of interpretation, but difficulties ought only to stimulate investigation.

Is the Ozarkian Tertiary or Quaternary? Finally, we are now prepared to return to the question of place of Ozarkian in the geological classification. After what has been said the answer

to this question is plain. Critical periods, as I have shown in previous papers, are the great landmarks separating the primary divisions of geological time—the eras. They are the comparatively fixed points between which we correlate periods as best we can by comparison. Now, if the Quaternary be indeed one of these and the last, then it is evident that the Ozarkian, being a time of great elevation and enlargement of continents, and therefore a period of lost record, belongs par excellence to that period. It is the most important and characteristic part, and the part which determined the whole succession of changes which inaugurated a new order of things, viz., Present; a new era, viz., the Psychozoic. The Tertiary was a period of comparative quiet, of gradual changes, and abundant life. The Ozarkian commenced the series of evolutionary changes which inaugurated a new era and is the most characteristic and important epoch in the series.

That the Ozarkian belongs to the Quaternary, therefore, is certain. But the question still remains: to what era should we attach the Quaternary? Upham thinks that to be consistent I ought to put it in the Psychozoic, because *man* was introduced in the Quaternary.[1] On the contrary, I believe it should be allied with the Cenozoic. The Permian, too, is a transition. revolutionary, critical period between the Paleozoic and Mesozoic, But after much discussion it has been put with the Paleozoic. The Laramie is the transition, revolutionary, critical period between the Mesozoic and Cenozoic. Again, after long discussion, it has been put in the Mesozoic. So, also, the Quaternary is the transitional, revolutionary, critical period between the Cenozoic and Psychozoic. After some discussion it will undoubtedly be put in the Cenozoic with the Tertiary. It is true that man, the characteristic dominant type of the Psychozoic, was introduced in the Quaternary. But here, also, the analogy with other critical periods holds good. A new era begins when the readjustment and the new order is established. Reptiles were introduced in the Permian, but the reign of reptiles did not

[1] Am. Nat., Vol. XXVIII, p. 980, 1894.

begin until the Trias. Mammals were introduced in the Mesozoic, and even true mammals — eutheres — probably in the Laramie, but the reign of mammals did not begin until the Tertiary. So, also, man was introduced in the Quaternary and possibly even in the Pliocene, but for a long time he struggled doubtfully for mastery with the great beasts of that time. His supremacy was not established until after the Glacial epoch, *i. e.*, with the Psychozoic.

All I insist on, however, is that the Quaternary, wherever it is put, must all go together. It must not be split and its most characteristic part separated and put in the Tertiary. There may be, indeed, some good reasons for putting it *all* in the Tertiary, and analogy will bear this out. For example, it is customary to make three periods in the Carboniferous, viz., the Mississipian, the Coal Measures, and the Permian, but there is a growing tendency to unite the Permian with the Coal Measures as its uppermost transitional stage. Again, we may divide the Mesozoic into Triassic, Jura, Cretaceous, and Laramie, but it is more usual and probably best to unite the Laramie with the Cretaceous as its uppermost transitional stage. So, also, it is customary to divide the Cenozoic into two periods, Tertiary and Quaternary, but it may possibly be better to regard the Quaternary as the final transitional stage of the Tertiary, and thus to divide the Tertiary into four epochs, the Eocene, Miocene, Pliocene, and Pleistocene. All I insist on is that its most characteristic part and that which determined the whole series of changes characteristic of this time should not be separated from the rest.

A PLEA FOR PSYCHOZOIC AS AN ERA.

I again take occasion to insist on the present, as the beginning of a new era — the Psychozoic — separated from the Cenozoic by the last great critical period, the Quaternary. This must be so if the Quaternary be indeed a critical period comparable with those that separated the previous eras. That it is such is shown by the fact that it has all the characteristics of such periods. It is characterized (1) by widespread oscillations of

the earth's crust; (2) by the formation or rejuvenation of great mountain ranges; (3) by the formation of new constructional forms, and the inauguration of a new cycle of erosion forms; (4) by great climatic oscillations; (5) by wide migrations and minglings of faunas and floras, and fiercer struggle for life, and rapid changes of organic forms by wholesale destruction of old forms and evolution of new forms; (6) by more rapid steps of evolution, but a partial obliteration of previous geographic diversity, and the inauguration of a new cycle of increasing diversity; and (7) by the introduction of a new dominant type —man, who is now becoming more and more the great agent of change in the new era, especially in organic forms.

There can be no doubt that we are now in the midst of a change more sweeping and rapid than has ever before taken place in the history of the earth, but which we imperfectly appreciate because we are in the midst of it, and therefore lose the perspective. Why then should we hesitate to recognize that the present is indeed one of the prime divisions of geological time? It is more: it is that which alone gives significance to all that precedes.

Joseph Le Conte.

AN ATTEMPT TO FRAME A WORKING HYPOTHESIS OF THE CAUSE OF GLACIAL PERIODS ON AN ATMOSPHERIC BASIS[1]

THERE are hypotheses and working hypotheses. The suggestion that the last glacial period was caused by the passage of the solar system through a cold region of space may be styled a hypothesis, but scarcely a working hypothesis in the geological sense, for it does not form the groundwork or incentive of geological inquiry. An astronomer might be moved to hunt for the cold spot, but it has no inspiration for the geologist. General suggestions of a possible cause do not reach the dignity of working hypotheses until they are given concrete form, are fitted in detail to the specific phenomena, and are made the agents of calling into play effective lines of research. The construction of a concrete working hypothesis suited to stimulate and guide investigation in a wholesome manner, and to take its place in competition with other hypotheses of like working potentialities, thereby inducing a more searching scrutiny of the phenomena and a more varied application of interpretations, represents the higher limit of present reasonable aspiration. It is much too ambitious to hope for a demonstrative solution of the origin of the earth's glacial periods by first intention in the present state of knowledge.

The hypothesis here offered is not worked out into satisfactory detail at all points, but it is hoped that it is sufficiently matured to justify a preliminary statement. In forming it, which has been the work of several years, I have found, or seemed to find, the phenomena of past glaciation intimately associated with a long chain of other phenomena to which at

[1] A brief statement of the salient features of this hypothesis was given in a paper entitled A Group of Hypotheses Bearing on Climatic Changes, JOUR. GEOL., Vol. V, pp. 653–683, Oct.–Nov. 1897. For earlier history see footnotes on pp. 654 and 681 of that paper.

first they appeared to have no relationship. This chain led on and on until it became connected with many of the most fundamental problems of geology. When once an inquiry into the history of the atmosphere and its possible functions in the past was raised, there seemed no resting place until the origin of the atmosphere — and with it the origin of the earth — was reached. The inquiry raised profound skepticism regarding some of the most firmly accepted doctrines of the original state of the earth, its internal constitution, and the great dynamic forces that have controlled the larger phases of its history. A series of new, or partially new, hypotheses relative to these fundamental phenomena seemed to be necessary to fill out the group of alternative theories requisite to cover the ground of legitimate doubt based on specific reasons for doubt. In other papers I have given a partial expression to the hypotheses framed to cover these points.[1] The exposition of these has not in all cases been sufficiently ample to give them good working form, but has perhaps been sufficient to show their general relationship to an atmospheric hypothesis of glaciation.

The hypothesis here offered is confessedly connected in my own mind with these ulterior and more fundamental hypotheses, but it does not seem to me that it is necessarily so connected. To be sure, if it is assumed, following a prevalent custom of the past, that the original atmosphere was a vast gaseous envelope embracing essentially all the carbonic acid that is now locked up in limestone and other carbonates, and all that is represented by coal and other carbonaceous matter, and that the atmospheric history has been essentially a progressive depletion of this original supply, I do not see how the proposed hypothesis can be entertained, at least for the earlier glaciations. But if it be

[1] A Group of Hypotheses Bearing on Climatic Changes, JOUR. GEOL., Vol. V, No. 7, 1897. The Ulterior Basis of Time Divisions and the Classification of Geologic History, *ibid.*, Vol. VI, No. 5, 1898. A Systematic Source of Evolution of Provincial Faunas, *ibid.*, No. 6, 1898. The Influence of Great Epochs of Limestone Formation upon the Constitution of the Atmosphere, *ibid*, Lord Kelvin's Address on the Age of the Earth as an Abode Fitted for Life, Science, N. S., Vol. IX, No. 235, pp. 889–901, June 30, 1899, and Vol. X, No. 236, pp. 11–18, July 7, 1899.

assumed that as early as Paleozoic times the atmosphere had some such constitution as it possessed in later geological times, and that its history has been a contest between the agencies of atmospheric supply and the agencies of atmospheric depletion, and that the constitution of the atmosphere at any time has been dependent upon the relative rates of supply and depletion, then the hypothesis may be entertained quite independently of all views of the origin of the earth and the atmosphere and of internal dynamics.

Previous advocacy of an atmospheric hypothesis.—The general doctrine that the glacial periods may have been due to a change in the atmospheric content of carbon dioxide is not new. It was urged by Tyndall a half century ago and has been urged by others since. Recently it has been very effectively advocated by Dr. Arrhenius,[1] who has taken a great step in advance of his predecessors in reducing his conclusions to definite quantitative terms deduced from observational data.[2] The great labor involved in this and the specific results springing from it place his contribution on a much higher plane than the general suggestions of those who had preceded him. Valuable as these general suggestions were, they must still be regarded as falling much short of working hypotheses, since no attempt was made to show that changes in the content of carbon dioxide of such a degree as would be compatible with the continuity of life and with other limiting geological conditions were quantitatively competent to produce the effects assigned them; nor were modes of inquiry into this essential matter suggested. It is one thing to point out a theoretical *causa vera*, and quite another thing to give good reasons for believing that it is quantitatively sufficient, and to open lines of inquiry for demonstrating that it is so. This Dr. Arrhenius has done and apparently with great success. While his results are doubtless to be regarded as subject to modification when more full and exact data are at hand,

[1] On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground, by SVANTE ARRHENIUS, Phil. Mag., April 1896, pp. 237–276.

[2] See review of his paper in this number of the JOURNAL, p. 623.

it is apparent upon inspection that they can be very largely modified and still fall within the limits of the conditions of the case. This will perhaps appear more evident in the course of the subsequent discussion. In so far as the deductions of Arrhenius and the accompanying views of Professor Högbom [1] fail to definitely postulate operative geological agencies competent to produce the requisite variations in the constitution of the atmosphere, and to give reasons for believing that such agencies were in operation at the times requisite to produce the effects assigned them, they fall short of furnishing an ample working hypothesis from the geologist's point of view. This, of course, is the function of the geologist rather than the chemist and the physicist. Professor Högbom has made a valuable contribution to the general doctrine of consumption and supply.

To form a good working hypothesis in a geological sense, it is furthermore necessary to assign subsidiary agencies working in an oscillatory manner correspondent with the oscillations of glaciation now so well authenticated by observation.

Specific requisites of a working hypothesis.—It is obvious that it is necessary at the outset to assign agencies capable of reducing the amount of the carbon dioxide of the atmosphere at the time of the glaciations. If there were no other glaciation than that of the Pleistocene period, and if there were no kindred phenomena needing to be elucidated at the same time, it might be sufficient to point to the well-known abstraction of carbon dioxide from the atmosphere in the formation of limestones and carbonaceous deposits, and there rest the case, with the implication that further production of limestones and carbonaceous deposits would insure further glaciation, and that the permanent and final winter of the earth is at hand. A very slight computation of the rate at which carbon dioxide is now consumed is sufficient to show that an effective depletion of the atmosphere is near at hand unless there be sources of supply approximately equal to the depletion. But recent depletion touches only the

[1] Svensk Kemisk Tedskrift, Bd. VI, p. 169 (1894). Quoted in Dr. Arrhenius's paper, p. 269.

easier part of the problem. Whatever may be thought of the supposed signs of cold periods at other early periods, the evidences of glaciation in India, Australia and South Africa near the close of the Paleozoic era are so abundant, so specific, and so well attested, that they cannot be ignored, and any hypothesis that assumes to account for glacial periods must take serious cognizance of these and must meet the strenuous issues that spring from their early age and from the mildness of the periods following them. It seems to the writer almost equally necessary to take cognizance of the salt and gypsum deposits of various periods, which imply degrees of aridity in relatively high latitudes scarcely equaled at the present day. If the atmospheric line is followed, it seems necessary to postulate a reduction of carbon dioxide near the close of the Paleozoic era — to say nothing of other early times — so effectual as to produce glaciation between 20° and 35° latitude on both sides of the equator, a glaciation the deposits of which aggregate a greater thickness than those of Pleistocene times, and whose oscillations, marked by thick accumulations of coal, were even more remarkable than those of the Pleistocene glaciation. If a depletion of the carbon dioxide of the atmosphere sufficient to produce this glaciation at this relatively early stage in geological history is postulated, it is necessary to assign agencies for the reënrichment of the atmosphere in carbon dioxide to account for the mild climates in high latitudes in Jurassic, Cretaceous, and Tertiary times. In short, it is necessary to assign competent operative geological agencies which shall produce effective depletion alternating with effective reënrichment of the atmosphere from an early period in its history down to the present time. If the salt and gypsum deposits, and the prevailing red beds, with arkose elements, be regarded as the products of exceptional aridity, and if this be assigned to the localization and intensification of heat and moisture due to the removal of carbon dioxide, as subsequently set forth, it is necessary to multiply the oscillations from enrichment to depletion very notably, and to extend the alternating action at least as far back as the close of the Silurian period

when the great saline deposits of New York, Ontario, Ohio, Michigan and adjacent regions were laid down.

Primary assumptions.— (1) It is therefore assumed as the working basis of the hypothesis that the carbon dioxide of the Paleozoic atmosphere was at certain stages not essentially greater than it is today, that at the specific epochs of great saliferous deposition and of glaciation it was reduced to a quantity notably less than the present content, while at other and intervening stages its amount exceeded the present content by some multiple —these latter periods being those in which the wide extension of marine epicontinental life took place. For myself, I am disposed to extend the assumption of a measurably limited atmosphere back to the very beginning. To this I am led in part by the conviction that the gravitation of the earth is incompetent to hold an atmosphere very greatly beyond the amount so assumed, and by the much more speculative consideration that the earth may have grown up by slow accretion rather than rapid concentration, and that hence the early development of the atmosphere was controlled by limitations much like those that have affected it in its later history. But, as already remarked, this assumption is not regarded as vital to the hypothesis. (2) Wrapped up in the foregoing postulate is an assumption of the essential correctness of the doctrine of Arrhenius that variations of the atmospheric carbon dioxide falling within limits compatible with life and with other geological phenomena, are competent to effectively change the thermal state of the atmosphere. This needs further statement.

The functions of carbon dioxide.— By the investigations of Tyndall,[1] Lecher and Pretner,[2] Keller,[3] Rœntgen,[4] and Arrhenius,[5] it

[1] Heat as a Mode of Motion, 6th ed., pp. 345–349, 1892. Contrib. to Mol. Physics, pp. 38. 117, 421, 1888.

[2] Sitzungsberichte des Akad. der Wissenschaften d. Wien (2). Vol. LXXXII, p. 851 (2), Vol. LXXXVI, p. 52.

[3] Am. Jour. Sci. (3), Vol. XXVIII, p. 190.

[4] Poggendorfs Annalen (2), Vol. XXIII, p. 1259.

[5] Phil. Mag., Vol. XLI, pp. 237–279.

A brief statement of the conclusions of these authors is given in the article of Mr. Tolman in this number, p. 586. See also his review of Dr. Arrhenius, p. 623.

has been shown that the carbon dioxide and water vapor of the atmosphere have remarkable power of absorbing and temporarily retaining heat rays, while the oxygen, nitrogen, and argon of the atmosphere possess this power in a feeble degree only. It follows that the effect of the carbon dioxide and water vapor is to blanket the earth with a thermally absorbent envelope. Their absence would leave the surface of the earth essentially exposed to the free impact and free radiation of the solar rays, measurably, though of course not entirely, as if the earth were devoid of atmosphere. A reduction or an increase in these constituents would produce corresponding partial effects. The general results assignable to a greatly increased or a greatly reduced quantity of atmospheric carbon dioxide and water may be summarized as follows:[1]

a. An increase, by causing a larger absorption of the sun's radiant energy, raises the average temperature, while a reduction lowers it. The estimate of Dr. Arrhenius, based upon an elaborate mathematical discussion of the observations of Professor Langley, is that an increase of the carbon dioxide to the amount of two or three times the present content would elevate the average temperature 8° or 9° C. and would bring on a mild climate analagous to that which prevailed in the Middle Tertiary age.[2] On the other hand, a reduction of the quantity of carbon dioxide in the atmosphere to an amount ranging from 55 to 62 per cent. of the present content, would reduce the average temperature 4° or 5° C., which would bring on a glaciation comparable to that of the Pleistocene period.

The amount of moisture in the atmosphere, other things being equal, is directly dependent upon the temperature, and the temperature in turn is dependent upon the amount of moisture in the atmosphere. This reciprocal dependence renders the aqueous

[1] The action has two phases that in an exhaustive exposition would need separate statement, (1) the absorption of solar rays before they reach the earth, and (2) the absorption of the rays radiated by the earth. The latter have longer wave-lengths on the average and are relatively much more affected by the constitution of the atmosphere.

[2] Dr. Arrhenius, loc. cit.

vapor a vacillating factor subject to the control of any other agency which increases or decreases the atmospheric temperature. Whenever therefore an increase of carbon dioxide raises the temperature, it increases the quantity of water vapor and this by its thermal absorption further increases the temperature and calls forth more vapor and this action and reaction continue in diminishing force until an equilibrium is established. A decrease in carbon dioxide decreases the temperature and thus lessens the water vapor, and this further lowers the temperature and inaugurates a reversed series of actions and reactions. Fluctuation in the quantity of carbon dioxide therefore is attended not simply by its own individual effects, but by these auxiliary effects also. The carbon dioxide becomes therefore the determinative factor, and the question of the thermal absorption of the atmosphere may be discussed for convenience as though it were solely dependent upon the fluctuations in the content of this constituent, although this will not be strictly exhaustive.

b. A second effect of increase and decrease in the amount of atmospheric carbon dioxide is the equalization, on the one hand, of surface temperatures, or their differentiation on the other. The temperature of the surface of the earth varies with latitude, altitude, the distribution of land and water, day and night, the seasons, and some other elements that may here be neglected. It is postulated that an increase in the thermal absorption of the atmosphere *equalizes* the temperature, and tends to eliminate the variations attendant on these contingencies. Conversely, a reduction of thermal atmospheric absorption tends to *intensify* all of these variations. A secondary effect of intensification of differences of temperature is an increase of atmospheric movements in the effort to restore equilibrium. Increased atmospheric movements, which are necessarily convectional, carry the warmer air to the surface of the atmosphere, and facilitate the discharge of the heat and thus intensify the primary effect. In the case of a naked earth, the radiant energy of the sun falling directly upon the tropical belt is concentrated in space, and subject to the minimum reflection; in high latitudes, the rays

are spread over greater space, and are subject to greater relative reflection because of the low angle of incidence. In the case of an earth swathed in a thermally absorptive mantle, the direct equatorial ray is absorbed in traversing the atmosphere to a less extent than the ray of higher latitudes because it penetrates a less depth of atmosphere, while the amount of reflection from the atmosphere is small in both cases, so far as the transparent elements are concerned. In so far therefore as the temperature effects are dependent upon the absorption of the incoming rays, the greater depth of atmosphere penetrated in the higher latitudes makes important compensation for obliquity of incidence.

In the case of a naked earth, or an earth clothed with a non-absorptive atmosphere, the solar rays which are tangential to the polar regions have no heating influence upon the earth, while in the case of an earth clothed with an absorbent atmosphere, similar rays are partially absorbed, and serve to warm the earth. In the polar regions, therefore there is a very radical difference between the effects of an absorbent and a non-absorbent atmosphere. The same holds true of the heating effects of the morning and evening sun. With a non-absorbent atmosphere, the tangential morning and evening rays pass through and are lost; in a thermally absorbent atmosphere, they are effectually retained.

In so far as the incoming rays are absorbed in the atmosphere their immediate effects are chiefly felt in its upper strata and their influence upon the surface of the earth is lessened. This is due to the fact that the upper regions are penetrated by rays of all the various wave-lengths that emanate from the sun, while the lower portions are penetrated only by such rays as are left after the selective absorption of the upper atmosphere. The degree of this absorption of the rays of long wave-lengths is such that comparatively little further absorption takes place in the basal portion of the atmosphere, according to the interpretations of Arrhenius. One effect of increasing the absorptive capacity of the upper air by increasing the amount of carbonic acid is an increase in the elevation of the strata chiefly heated by the

incoming rays and the consequent reduction of the thermal gradient of a vertical column of the atmosphere. As a result there is less effective tendency to convection and less discharge of heat from the atmosphere.

In high latitudes, besides this effect, it is also to be noted that with an increase of the absorptive capacity of the upper atmosphere, rays that previously passed through the higher strata with little absorption are arrested and contribute heat to the upper air. The same is true of morning and evening rays at high elevations.

In the case of the outgoing rays, which are absorbed in much larger proportions than the incoming rays because they are more largely long-wave rays, the tables of Arrhenius[1] show that the absorption is augmented by increase of carbonic acid in greater proportions in high latitudes than in low; for example, the increase of temperature for three times the present content of carbonic acid is 21.5 per cent. greater between 60° and 70° N. latitude than at the equator. The maximum thermal effects also lie in higher latitudes for the summer months than for the winter months. On the other hand, when the carbonic acid is reduced to 0.67 of the present content, the maximum winter variation is felt between 30° and 40° N. latitude. If the carbonic acid be further reduced, the maximum variation found by extrapolation falls at and below 30°, the latitude of the Carboniferous glaciation. It is not intended, however, to imply that this would be sufficient in itself to produce that glaciation.

An atmosphere having a relatively large percentage of carbon dioxide and water, *i. e.*, an absorptive atmosphere, has a higher heat content than a non-absorptive one, and its circulation in latitude more effectually equalizes the temperature with the same degree of movement.

Similar considerations are applicable to the effects of land and water areas. In so far as the atmosphere absorbs the incoming rays in passing through it, the amount that reaches the surface of the earth is reduced. To this extent the possibility of

[1] Loc. cit., p. 266.

differential effects between the sea and land is lessened. On the other hand, in the absence of absorptive and diffusive effects, the tropical rays fall with full intensity upon the surface. On the land they promptly heat the immediate surface, and the heat is as promptly radiated away. On the sea, neglecting reflection, they penetrate deeply into the water until they are absorbed. The upper layer of the sea is therefore heated to a notable depth, and radiates its heat away with relative slowness. The result is an intensification of the differences in average temperature of the land and the sea. This action is quite familiar, but perhaps not the point here urged—that this difference is dependent on the atmospheric effects upon the incoming as well as outgoing rays. If the atmosphere were so far robbed of its absorbent factors, carbon dioxide and water, as to give great intensity to this differential effect, the result might be an average temperature of the land below the freezing point, while that of the sea might be relatively warm. It seems clear that at some point short of an absolute thermal transparency a stage would be reached where the average temperature of the land would sink below zero, while yet the sea, barring convection in latitude, would retain a comparatively mild temperature. There would then apparently arise, even in low latitudes, the conditions of glaciation.

Without following out these lines into greater detail, the more pertinent deductions may be summed up in the following propositions: A reduction of the thermal absorption of the atmosphere would intensify the differences of temperatures between (1) the basal and the upper portions of the atmosphere; (2) low and high latitudes; (3) land and sea; (4) night and day; and (5) the seasons. In short, it would intensify temperature differences generally, and would lead to (1) greater local heat, as well as greater local cold; (2) to greater local dryness, as well as greater local moisture; (3) to more intense movements of the atmosphere in the endeavor to maintain equilibrium; and (4) to lower average temperature. The effect of reducing the absorbent factors is the intensification of differences.

On the other hand, an increase in the absorptive factors renders ineffectual, in a corresponding degree, the variations of altitude, of latitude, of land and sea, of day and night, and of the seasons, and conduces to an equable and mild temperature, to gentle and yet thermally effective circulation, and to higher average temperature. As Arrhenius has remarked, "The geographical, annual, and diurnal changes of temperature would be partly smoothed away if the quantity of carbonic acid was augmented. The reverse would be the case (at least to a latitude of 50° from the equator) if the carbonic acid diminished in amount."[1]

AGENCIES OF DEPLETION AND ENRICHMENT

It now becomes necessary to assign agencies capable of removing carbon dioxide from the atmosphere at a rate sufficiently above the normal rate of supply, at certain times, to produce glaciation; and on the other hand, capable of restoring it to the atmosphere at certain other times in sufficient amounts to produce mild climates.

These agencies on both sides belong to two classes, the permanent and the temporary, and the distinction has practical importance.

Sources of permanent loss.—Permanent depletion results from the consumption of carbon dioxide in the transformation of the silicates of the original earth, and of volcanic products into the carbonates of the secondary strata. It is fairly safe to assume that the original earth's surface was composed of material of the general class represented by the igneous rocks and the basement complex. These, it is needless to say, consist largely of silicates with which are associated certain quantities of certain gases to be considered more fully hereafter. These silicates, where exposed to the weathering action of the atmosphere, become decomposed and take the form of carbonates (with less quantities of sulphates, phosphates, etc.) and of residual silicates and oxides (kaolin, quartz, ferric oxides, etc.). Neglecting the minor transformations which do not concern us here, the operation may be

[1] Loc. cit., p. 268.

characterized as carbonation, and consists essentially of the substitution of carbonic acid for the silicic acids. The carbonic acid is derived, in the main, from the atmosphere. In their soluble condition, the carbonates so formed are largely bicarbonates. This is the only form in which calcium carbonate is appreciably soluble, and the same is true in a less degree of magnesium carbonate. The monocarbonates of potassium and sodium are highly soluble, but the bicarbonates also appear in solution. Practically the carbonates of these alkalis usually become changed into other salts (sulphates, chlorides, etc.) and the carbon dioxide that may have been temporarily locked up with them is set free by the change, or enters some other combination. The magnesium and calcium carbonates are also in part changed to other salts. But for the purposes of this discussion, which is concerned chiefly with the final issue and not with the transient stages of these compounds, it is sufficient to note that the chief result of the decomposition of the original silicates is the formation of calcium and magnesium carbonates, which are deposited as limestones and dolomites and thus lock up carbon dioxide at the expense of the atmosphere. The amount so taken from the air in the known geological periods has been variously estimated at from 20,000 to 200,000 times the present content; indeed estimates have gone beyond the last figure. When it is considered that 44 per cent. of all pure limestone and a higher per cent. of all pure dolomite is carbon dioxide, it is obvious that the total quantity is very large, and its computation is dependent upon the estimate of the total amount of limestone and dolomite in the crust of the earth.

A second source of permanent loss consists of the consumption of carbonic acid by plants and the fixation of the carbon in carbo-hydrates, hydro-carbons and other carbonaceous compounds which ultimately take the form of coals, bitumens, oil, gas, and perhaps most important of all, disseminated organic matter in the sedimentary series.

Exceptions.—Some hydro-carbons have probably been produced by inorganic action, notably those derived from carbides

(Moissan) formed within the earth and extruded from it. Some carbonates probably have been formed by carbonic acid contained within the rocks or extruded from the interior. In certain phases of the problem, deduction is to be made for such carbonaceous compounds and carbonates as are formed in the sea by marine plants and other agencies which derive their carbonic acid from the sea water; but in the general discussion of the question, the carbonic acid of the sea must be reckoned in with the carbonic acid of the air, for the two are in equilibrium and constitute essentially and potentially one body. The necessity for this assumption will be more obvious when we come to discuss the function of the ocean in influencing the constitution of the atmosphere.

Sources of permanent gain.— Over against these sources of secular loss there are certain sources of gain. If the assumption that the constitution of the atmosphere has varied through only moderate limits within the known ages be adopted, it is necessary to postulate sources of supply of a competency approximately equal to the sources of loss. The data for such postulation are exceedingly unsatisfactory and a function of the hypothesis should be to stimulate investigation in these lines which have been barely touched by serious inquiry.

a. Gain from the interior.— The crystalline rocks of the surface of the earth have been shown by the recent examinations of Tilden [1] to contain very notable quantities of gas, consisting of hydrogen in preponderance, carbon dioxide and carbon monoxide in large percentages, and nitrogen and marsh gas in small quantities, with water vapor, but with a practical absence of oxygen. Twenty-five analyses, including ancient and modern volcanic and even some metamorphic rocks, gave an average volume of gas equal to about four and a half times the volumes of the containing rocks. A computation on this basis shows that an atmosphere equivalent in mass to the present one would be contained in a very superficial rind of the earth, and that if this volume of

[1] On Gases Contained in Crystalline Rocks and Minerals: W. A. TILDEN, Chemical News, April 9, 1897.

included gases be constant for the whole body of the earth, it contains potentially a multitude of atmospheres.

It is a familiar fact that enormous quantities of gases are ejected from volcanoes during their active periods. It has been very generally assumed that these gases and vapors, among which steam vastly preponderates, have a surface origin, and there can be no doubt that this is true of some notable part; but, on the other hand, there is abundant ground for the belief that another notable part is brought from the interior and is a real contribution to the earth's atmosphere and hydrosphere. It may not be possible at present to demonstrate this, but inquiry in this direction is invited. There seem to be no means of estimating from present data even approximately the volume of gas which is given forth, but it is certainly large. There are grounds for believing that the gases of the interior escape by other than volcanic vents. The deep rending and sharp shock of the earth in seismic movements, the stresses and fissuring of readjustments, the disintegration of crystalline rocks, and the resources of slow diffusive penetration are among these. So far as the setting free of carbon dioxide by decomposition of the containing rock is concerned, it is to be noted that the chemical action which sets it free involves a consumption of carbon dioxide very greatly in excess of the amount liberated, so that, as computation will show, the total effect of the process is one of loss which the internal gases only very slightly modify. This, of course, is not true of mechanical disintegration.

b. Exterior sources of gain.—The meteorites which are constantly falling to the earth contain included gases, often in great volume. They also contain carbonaceous matter which is partially burned in passing through the air. The nature of the included gases is notably similar to those of the crystalline rocks, hydrogen and carbon dioxide being the leading constituents with nitrogen in very subordinate amount and free oxygen essentially absent.[1] Water vapor appears in both meteorites and

[1] See numerous papers of A. W. WRIGHT in Am. Jour. Sci., notably Gases contained in Meteorites, Am. Jour. Sci, 3d series, Vol. XII, No. 69, Sept. 1876.

crystalline rocks, but it is impossible to say how far it was absorbed from terrestrial sources. It has even been suggested that all the gases both of meteorites and of the crystalline rocks were simply absorbed from the air and not brought in from without; but their proportions are so different from those of the air that it would be necessary to assume an extraordinary selective power to make this possible; for oxygen must be wholly rejected as a gas; nitrogen, though greatly preponderant, must be almost neglected; carbon dioxide must be absorbed in great quantities relatively; carbon monoxide, though very rare in the atmosphere, must be taken in abundantly; while the hydrogen, which is scarcely detectable in the atmosphere, must be absorbed in superlative amounts. It is difficult to conceive how a meteorite passing rapidly through the air can have absorbed many times its volume of an element which does not appear in the air in detectable quantities. However, I am unable to say that the analyses were made sufficiently soon after the fall of the meteorites to make this point conclusive. But, at any rate, the hypothesis of selective absorption is confronted with grave difficulties and the alternate hypothesis that the gases are brought to the earth in the meteorites seems the more probable. The emanations from comets support the view that meteorites are charged with gases in extra-terrestrial regions. Here again inquiry is needed and experimental tests are obviously suggested.

If gases are brought in with meteorites, it is probable that independent molecules are flying through space and are caught up by the earth. The modern doctrine of molecular velocities, which holds that gases are liable to escape, and presumably are escaping constantly, from planetary bodies, carries the presumption that individual molecules are flying through space with some degree of frequency. Astronomical phenomena, to be sure, seem to indicate that the quantitative value of these cannot be very great, but as definite data are yet wanting and we are dealing with vast lapses of time and slow processes of depletion, making need for slow processes of accretion only, this agency may

deserve a place among the undetermined sources of atmospheric material.

It is among the possibilities that the sun itself may be a direct source of atmospheric feeding. The speed at which the solar prominences are projected from the sun has been observed to exceed the parabolic velocity of the sun;[1] that is, the rate of projection is such that if the outer atmosphere of the sun does not effectually interfere, the gases are shot away beyond even the sun's control. A much less speed could carry the gases to the earth, so that, unless the outer atmosphere of the sun interposes effectual barriers, it is not improbable that gases are thrown as far out as the orbit of the earth. The earth probably cannot hold hydrogen, the chief gas of these prominences, permanently as such, but it may do so when combined with oxygen. The shooting of solar hydrogen through our atmosphere would lead to the formation of water, because, even at ordinary temperatures, such of the molecules of oxygen and hydrogen as collided with the requisite velocity would enter into union. There seem therefore grounds for placing this among the possible but undetermined sources of supply for our atmosphere and hydrosphere. When the mystery of the zodiacal light and the gagenshein shall be solved, it is possible that demonstrative evidence of our relations to the extreme projections of the solar atmosphere may be available.

In the present state of extreme uncertainty relative to all these possible sources of supply, a hypothesis which necessarily involves them proceeds with uncertain steps and must perforce wait patiently for more definite determinations, but the pressing of a hypothesis which lays emphasis upon them is but giving effect to the fundamental mission of all working hypotheses.

VARYING RATES OF ACTION

By the terms of the hypothesis the state of the atmosphere at any time is dependent upon the relative rates of loss and gain.

[1] The Story of the Sun, by SIR ROBERT BALL, pp. 185–188; The New Astronomy, LANGLEY, p. 61.

It is of supreme importance therefore to consider irregularities in the action of the sources of loss and gain.

Varying rates of gain.—The constancy or irregularity of the sun's contribution—assuming it to make a recognizable contribution—is quite unknown. It would presumably be dependent upon the internal explosive action of the sun concerning which all thought is as yet highly speculative. So far as its relations to geological periods are concerned, it would probably be either an essentially constant factor or one which would not fall in systematically with any special phase of geological progress, and could not be regarded as a coöperative factor in any definite phase. It might be progressively increasing, as the sun concentrates, or progressively diminishing.

Much the same is to be said with regard to possible sources of supply from meteoric and similar extra-terrestrial sources.

The extrusion of gases and vapors from the interior has been presumably periodic, because the conditions of molten eruption and of mechanical disruption have probably been periodic rather than constant. No specific determination of the periodicity of volcanic action has yet been made out, but the testimony of present geological data is to the effect that vulcanism has been more frequent and intense at certain periods than at others. This is clearly true for individual grand divisions of the earth, and seems to be true of the earth at large, notwithstanding the fact that vulcanism was a more or less local phenomenon. While a definite periodicity, specifically connected with other phenomena, cannot now be affirmed, the tentative proposition that vulcanism has been more abundant in great periods of readjustment than in periods of quiescence may be entertained. The connection with those periods seems sometimes to have been very intimate and immediate, and at other times more remote. So far as disruption of the rocks constitutes a means of escape for internal gases, there should obviously be a close connection with periods of readjustment. In a rather general and uncertain way, then, it would seem necessary to assume, in a working hypothesis, that the enrichment of the atmosphere from internal

sources has proceeded more rapidly at or about the periods of crustal disturbance. This, as we shall see, coincides practically with the periods of depletion from atmospheric action on the surface, and hence, so far forth, the two processes tend to neutralize each other and preserve the constancy of the earth's atmosphere. The hypothesis must therefore recognize that it was only when one agency fell behind the other in its competency that its specific results became manifest, and then only by the difference in their respective effects.

Varying rates of loss.—The rate of chemical action of the atmosphere on the surface of the rocks is believed to have been intimately connected with the extent and height of the land area, considering the earth as a whole. There were qualifying conditions, as we shall see, but notwithstanding, this is regarded as an important law. It is made a fundamental postulate of the hypothesis, and the vitality of the hypothesis as a working instrument of investigation hangs very largely upon it. It is obvious that the greater the surface area of rock exposed to the effective action of the atmosphere, the more rapid will be the rate of disintegration, other things being equal, and the more rapid the consumption of carbon dioxide. [1]

The rate of carbonation of the rock is dependent upon elevation as well as superficial area. The disintegration of rock is the most active by far in the zone lying between the surface and the level of permanent underground water, technically the water table. It is in this zone that the atmosphere and the moisture of the earth combine to give the greatest chemical

[1] Oxygen is also consumed in the decomposition of average rock, but in less amount than carbonic acid, and as the amount of oxygen in the air is very much larger than that of carbon dioxide, the part consumed is far less critical. In an exhaustive study of the constitutional history of the atmosphere, the loss and gain of oxygen must be considered, and certain very interesting and important phases of atmospheric variation are probably connected with the production and consumption of the oxygen, but, as indicated, they are much less immediate and critical in the consideration of thermal problems with which our hypothesis is more especially concerned, and for the sake of simplicity the oxygenation of the rocks may be temporarily neglected; and for like reasons the many minor reactions may also be ignored and attention confined to the carbonation.

activity. It is established by the most ample observation in mining, that below the permanent water level disintegration has made slow progress compared with that in the zone above the water level. Now the thickness of the zone between the surface and the permanent water level is intimately dependent upon the general altitude. In a continent reduced approximately to base level, this zone is exceedingly thin. In a region much elevated and deeply dissected by erosion, the thickness of the zone is very much greater. As between a continent with an average elevation of 2000 feet, at the climax of dissection following a crustal readjustment, and a continent of similar area with an average elevation of 300 feet, during a period when it is approximately at base level, the average depth of the aërated zone above the water level, probably varies more nearly with the square of the elevation than as a direct multiple of it. It is improbable, however, that the chemical action is augmented at so great a ratio. Probably greater warmth and more abundant vegetation are correlated with the lower altitudes, and both these aid chemical action. This in turn is somewhat offset by the greater mechanical disaggregation which results from changes of temperature and from gravitative influence in the more elevated condition. Making all allowances that seem required for the offsetting factors, it would still appear that the elevated condition increases the activity of decomposition in a very notable degree.

Below the permanent water level, the advantage probably also lies greatly with the higher elevation. The action of surface water upon the deeper rock is dependent upon the unbalanced hydrostatic pressure which promotes underground circulation and forces the water through the crevices and pores of the rock. If the underground water stands near sea level, there is little unbalanced hydrostatic pressure to promote active circulation and thereby carry the surface waters, enriched with atmospheric gases, down into the lower strata and bring them into action. The atmospheric waters precipitated upon the surface run away chiefly at the surface, and fail of the contact necessary for action. On the other hand, in an elevated region

there is a potential hydrostatic pressure measured by the difference of altitude of the surface of the ground water and the surface of the sea which tends to cause the waters to flow through the rock and thus find a tortuous way to the equilibrium of the sea level. A deep underground circulation is therefore a function of high altitude, and, correlated with that circulation, is chemical activity proportionate to the enrichment of the surface waters with chemically active agencies, in the present instance, carbon dioxide in particular. This deeper circulation, correlated with hydrostatic pressure, is enhanced by the greater degree of fissuring of the rock which attends elevated tracts, for in the process of elevation, writhing and cracking are notable incidents, and, in addition to this, the gravitative tensions which necessarily attend an elevated position lend their aid in the production and opening of crevices. Precisely the opposite conditions prevail at low levels. The protruding superficial portion of the land is the most fissured part and when it has been cut away by erosion the basal remnant is normally less open to the penetration of water. It would appear from a consideration of these several associated influences that disintegration and decomposition are facilitated by elevation in a very important degree.

If, therefore, there were times in the history of the earth when there were general readjustments of its bodily form to accumulated internal stresses, resulting in extensive elevations, embracing not only the formation of mountains and plateaus, but the general warping outwards of the continental platforms, and the bowing downwards of the ocean basins, attended by the withdrawal of the sea, so that the land area was extended and, at the same time its average elevation increased, and a portion of it rent and crushed, it is believed that the carbonation of the rocks must have been accelerated by some notable multiplier and that the rate of consumption of the carbon dioxide of the atmosphere must have been correspondingly promoted ; and this is made an important postulate of the hypothesis.

At least two periods of such very general and notable

elevation appear to be well authenticated by present geological data, imperfect as they are for certain quarters of the earth. These periods occurred near the close of the Paleozoic and of the Cenozoic eras respectively. Closely connected with these two periods are two well authenticated glacial periods.

If, on the other hand, there were periods of prolonged quiescence of the earth's body during which the lands were cut down well towards base level, they would be accompanied by a progressive slackening of the rate of disintegration, and a corresponding reduction in the rate of atmospheric loss of carbonic acid, giving opportunity for the agencies of repletion to overtake and surpass the agencies of depletion. It is believed that there was a series of such periods among which the Cretaceous is best authenticated.

During a prolonged period of relative quiescence the encroachment of the coast lines upon the land, if elevated, becomes notable. In addition to this, the material removed from the land and deposited in the sea raises the water level, and when the degradation is notable this rise amounts to an appreciable factor. This aids the coast action by lifting it above the restraining influences of its own products, which, by shoaling the water off shore, tend to break the force of wave action. The notion is also entertained that during periods of readjustment the continental masses are apt to be lifted beyond the plane of perfect isostatic equilibrium, and that there follows a tendency to slowly creep back into equilibrium, accompanied by a general tendency of the continental platform to flatten out under gravitative stress. The continental platforms are to be regarded as having elevations above the abysmal ocean bottom of perhaps 12,000 feet, and, as their average gravity is two and a half to three times that of the water which surrounds them, there remains a large excess of gravitative stress tending to cause the continents to spread laterally.

The combined effects of these agencies is a transgression of a thin edge of the sea upon the land. Now, such extensive transgression took place on all the great continents in the Upper

Cretaceous period, and this fact may be taken as indicating that the planation which reached so pronounced an expression on the American continent at that period affected nearly or quite all the continents in some similar measure. An inspection of the whole range of geological history shows periods of similar transgression accompanied by the development of luxurious and cosmopolitan marine faunas of the shallow-water type which in themselves imply the conditions here postulated.[1]

If this be a correct view it is obvious that at such periods the areas of land exposed to atmospheric action were notably reduced by sea encroachment, and that at the same time the lowness of the land greatly limited the depth of atmospheric activity by reducing the zone between the surface and the water-table and by reducing the hydrostatic penetration of surface waters. As already remarked, there is to be counted in offset probably warmer temperature, a higher degree of moisture, and a more abundant vegetation, but it is not believed that this approaches, even remotely, to a full offset to the reduction due to low elevation and reduced area.

If the foregoing views are correct there were certain periods in the history of the earth when carbonation proceeded with multiplied activity, separated by other periods during which its activity was greatly reduced. The intensification and the reduction differ by some notable multiplier of the average rate.

In working application, the hypothesis tentatively recognizes as periods of land extension attended by rapid carbon dioxide consumption, (1) the close of the Silurian and the opening of the Devonian, (2) the Permian and early Triassic, and (3) the Pliocene and Pleistocene. To this category may perhaps also belong, though the evidence at present is less adequate, (4) the early Cambrian, (5) the closing Ordovician and opening Silurian,

[1] For further statement of these views, see The Ulterior Basis of Time Divisions and the Classification of Geologic History, JOUR. GEOL., Vol. VI, No. 5, July–August, 1898, pp. 449–462; A Systematic Source of Evolution of Provincial Faunas, JOUR. GEOL., Vol. VI, No. 6, Sept.–Oct., 1898, pp. 597–608; The Influence of Great Epochs of Limestone Formation upon the Constitution of the Atmosphere, *ibid.*, pp. 609–621.

(6) the close of the Jurassic and the opening of the Lower Cretaceous, and (7) the transition period between the Cretaceous and the Eocene. In these periods there are evidences of declared intensifications of climatic influence expressed in widespread and thick deposits of salt and gypsum and in great series of red sandstones and marls, and, in the two most notable cases, by pronounced glaciation in middle and low latitudes.

On the other hand, it regards the following as periods of sea extension attended by the active freeing of carbon dioxide through the agency of prolific lime-secreting life, as hereafter set forth: (1) the middle Ordovician, (2) the middle Silurian, (3) the sub-Carboniferous, (4) the late Jurassic, (5) the Upper Cretaceous, and (6), less notable, the later Eocene and earlier Miocene. During these periods there is evidence of extensive limestone deposition spreading out widely on the continental platforms, attended by very mild and equable climates very nearly uniform for all latitudes.

SOURCES OF TEMPORARY LOSS AND GAIN

The discussion has thus far taken note of the original carbonation of the silicates of crystalline rocks only. These crystalline rocks, according to Dr. Tillo,[1] occupy something over 20 per cent. of the surface of the land. There remains nearly 80 per cent. occupied by secondary rocks which now claim attention.

Sources of temporary loss—The function of the secondary deposits. —To a large extent the material of the secondary deposits underwent chemical decomposition and carbonation preliminary to its deposition, indeed as a prerequisite to its derivation. In so far as this process was incomplete in the earlier stages, it was continued during any subsequent state of exposure, but this action belongs under the preceding head of original carbonation.

In the erosion of tracts of secondary rocks the limestones and dolomites are dissolved and carried down to the sea essentially as bicarbonates. In the strata they existed as monocarbonates. Their solution involves the taking up of a second

[1] Berghaus Atlas.

equivalent of carbonic acid to render them bicarbonates, and this second equivalent is derived essentially from the atmosphere. There is herein a source of temporary loss, temporary because the second equivalent of carbon dioxide remains associated with the bases in the sea only until deposition takes place, when it is set free. It is to be noted that a second equivalent is also taken up in the formation of original carbonates if they are dissolved. As the crystalline rocks occupy only a little more than 20 per cent. of the land surface and are probably not removed as fast as the secondary rocks, not more than about one fifth, probably not more than one tenth, of the bicarbonating carbon dioxide is associated with original carbonation. The remaining four fifths or more are occupied in bicarbonating and dissolving the calcareous and magnesian portions of the secondary rocks. It follows that the ratio of carbon dioxide now taken out of the atmosphere as second equivalent in any unit of time, to that taken out as first equivalent, is probably fully five to one, and not unlikely as high as ten to one. This ratio would not necessarily hold for past periods, but in all those under consideration the second equivalent was undoubtedly very much greater than the first.

Accepting, for the purposes of a rude estimate, the data of T. Mellard Reade,[1] the amount of carbon dioxide removed annually by original carbonation, reckoned by proportional area, is 270 million tons, the amount temporarily removed as the second equivalent of the bicarbonates is 1350 million tons ; the amount simply transferred from the land to the sea as the first equivalent of the carbonates previously formed is 1080 million tons ; the total mass taken from the atmosphere annually being therefore 1620 million tons, and the total mass removed to the sea 2700 million tons. Besides uncertainties in the original estimate of Reade, the first item is subject to correction (probably large) for the slower rate of disintegration of the crystalline rocks. This is, however, somewhat offset by weathering action on the silicates that remain undecomposed in the secondary rocks, and on

[1] Addresses, Geol. Soc. of Liverpool, 1876 and 1884, quoted in Dana's Manual, p. 191.

the late volcanics which are not all included in the 20 per cent. of the land area reckoned as crystalline. The second item is subject to correction to the extent that the salts were normal carbonates and not bicarbonates.

Reciprocal sources of temporary gain.—The second equivalent of the carbonates in the ocean is subject to easy removal under suitable conditions, and reënriches the atmosphere by diffusion into it from the ocean. The conditions under which this is set free are of critical importance to our hypothesis. We have to consider (*a*) saturation, (*b*) chemical reactions and dissociations, and (*c*) organic action.

a. Absence of general saturation.—In the absence of other agencies of removal the accumulation of calcium bicarbonates in the ocean would go forward to the point of saturation, if there were a sufficient amount producible. It would then be deposited as limestone, and the second equivalent of the carbon dioxide would be set free. There is little reason to think, however, that general saturation has been reached during the known portion of the earth's history. In local basins subject to peculiar conditions, saturation certainly has been attained, as the marls of the great saliferous deposits testify. The present approach to oceanic saturation in calcium carbonate is apparently only about 40 per cent. If the ocean in former times had reached saturation in calcium carbonate and any notable precipitation had followed, the precipitate should appear as a distinctive constituent of the clastic deposits. While calcareous matter which might be so interpreted occurs in some of these deposits, there is a notable absence of anything of the kind in many others where it might be expected, and the general character of the sandstones and shales seems more concordant with the accepted view that they were laid down in waters that did not, except in special cases, directly deposit calcareous matter. In view of the probable presence of lime-secreting organisms, the problem is generally rather to account for the paucity of calcareous matter than its abundance in the clastic deposits. The explanation is doubtless found in the undersaturation of the sea water and its ability

to dissolve calcareous relics. This view is supported by the partially dissolved condition in which calcareous fossils are so commonly found in the sediments of practically all the ages. The inference, therefore, to be drawn from the character of the sediments, and from the partial solution of calcareous fossils, is that the ocean, as a whole, has not generally been saturated with calcium bicarbonate during its known history. Murray has made us aware that at the present time the greatest depths of the ocean dissolve calcareous relics so freely as to prevent their accumulation.

b. Inorganic chemical reactions. — Viewed comprehensively the sea water consists of such solutions as have been carried down from the land in past times, modified by concentration and deposition. No important constituent has been totally removed. The land and sea waters have therefore the same fundamental constitution, but the salts of the former enter the sea in a more dilute form and in different proportions from those contained in the latter. Aside from organic action, and from exceptional inorganic agents such as may arise from submarine volcanic action and like incidental sources, essentially all occasion for chemical reaction when land waters are added to sea waters, is limited to a readjustment of the equilibriums of the common constituents of the two commingling waters. Following the simple doctrines of the old familiar "chemistry of results," the addition of a dilute solution of salts of the alkalis and alkaline earths to a more concentrated but not saturated solution of the same salts would neither occasion precipitation nor the evolution of gas, for every acid is mated with a base, and all are much below the point of saturation. According to the old interpretation the bases of the sea salts are, in the main, mated to stronger acids than those of the land waters, and these combinations will not be changed on the entrance of the latter. So, also, the small amounts of strong acids of the land waters are already mated with the strong bases in the main, and largely form the same combinations as those of the sea waters. Such interchanges as follow involve a double reaction essentially without the freeing

of acid or base. Under the old method of interpretation the sea salts, according to Dittmar, consist of —

	Percentage	Total Tons
Sodium chloride	77.758	$35{,}990 \times 10^{12}$
Magnesium chloride	10.878	$5{,}034 \times 10^{12}$
Magnesium sulphate	4.737	$2{,}192 \times 10^{12}$
Calcium sulphate	3.600	$1{,}666 \times 10^{12}$
Potassium sulphate	2.465	$1{,}141 \times 10^{12}$
Calcium carbonate	0.345	160×10^{12}
Magnesium bromide	0.217	100×10^{12}
	100.000	$46{,}283 \times 10^{12}$

A rude average of the composition of land waters and of the amounts of salts carried to sea annually, founded on the estimates of T. Mellard Reade, is here given for comparison.

	Approx. percentage	Tons annually
Calcium carbonate	50	$2{,}700 \times 10^{6}$
Calcium sulphate	20	$1{,}080 \times 10^{6}$
Magnesium carbonate	4	216×10^{6}
Magnesium sulphate	4	216×10^{6}
Sodium chloride	4	216×10^{6}
Potassium and sodium, Sulphates and carbonates	6	324×10^{6}
Silica	7	378×10^{6}
Other substances	5	270×10^{6}
	100	$5{,}400 \times 10^{6}$

These tables do not embrace the second equivalent of carbonic acid.

From these data it appears that it would require only a little over eight and one half million years for the land waters to bring in a gross amount of salt equal to that of the ocean, but it would require very different periods to bring in the individual constituents. It would take 166 million years to bring down the sodium chloride, but only about 1.5 million years to bring down the calcium sulphate, and only about 60,000 years to bring down the calcium carbonate. It appears therefore that there must be agencies constantly removing the calcium carbonate and the calcium sulphate at relatively high rates. These particular figures are subject to all the uncertainties involved in

Reade's primary estimate, but they probably represent approximately the relative ratios, and show the general nature of the eliminations that are requisite to change accumulating land waters into sea waters.

While these general statements of the nature and limitations of chemical action, based on the more familiar doctrines of the older chemistry, are doubtless essentially true, the refinements of modern chemistry teach that there is an intricate series of dissociations and exchanges of acidic and basic factors, and of the various ions, in an effort to establish and maintain a new equilibrium between the salts, required by their new proportions and their new states of dilution. As the land waters contain a relatively large percentage of bicarbonates of calcium and magnesium, the readjustment affects these especially, with the result that probably a minor percentage of the second equivalent of carbon dioxide is set free. It seems necessary to state this with qualification on account of the extreme complexity of the reactions, and the incompleteness of existing data; but the Challenger, and similar investigations show that the quantity of second equivalent of carbon dioxide is less than sufficient to raise all of the carbonates into bicarbonates. This deficiency is apparently limited to 20 per cent. or less of the theoretical amount required. More rigorous experimental determination is, however, greatly needed.

It is probable that the second equivalent of the land waters is deficient in some like degree, but this has not been experimentally determined. If this be true, it must reduce the estimate of the carbon dioxide brought down to sea, and also the amount set free by dissociation. The total amount of carbon dioxide which may be supposed to be set free by inorganic reaction in the sea in its present state of concentration, is therefore probably much less than 20 per cent. It is obvious from the preceding considerations, and others that will follow, that to maintain the atmospheric status even approximately there must be a nearly or quite complete return of the second equivalent of carbon dioxide by some means. This is also implied by the fact that

the oceanic deposits are not bicarbonates in any notable degree. The chief agencies of this return are held to be organic, and will be considered presently.

The chief compounds of both the land and sea waters are sodium, potassium, magnesium and calcium chlorides and bromides; sodium, potassium, magnesium and calcium sulphates; sodium, potassium, magnesium and calcium carbonates and bicarbonates; in other words, every combination which may take place between the acids and bases involved. Besides these salts there are, theoretically at least, the several acids and bases and a complete series of ions as well. There is a continuous dissociation and reunion in the effort to maintain equilibrium. The extent of the dissociation is dependent, among other things, notably upon the degree of concentration of the solution and upon its temperature. In an especial degree the extent of the freeing of the second equivalent of carbon dioxide is believed to be dependent upon this dissociation as influenced by temperature, and it is thus a vital consideration in realizing the function performed by the ocean during glacial episodes when its temperature was greatly changed. This function is made the subject of a special study in the paper of Mr. Tolman in this number of the JOURNAL.[1]

Mr. Tolman's studies have been founded upon Dittmar's experiments, and seem to show that the amount of carbonic acid freed from the bicarbonates by dissociation is very sensibly influenced by such changes of temperature as are necessary, according to the deductions of Dr. Arrhenius, to produce extended glaciation, on the one hand, and a mild climate in the arctic regions, on the other. In this he finds support for the suggestion which I made in a previous paper[2] that the ocean during a glacial episode instead of resupplying the atmosphere, in the stress of its impoverishment, would withhold its carbon dioxide to a certain extent, and possibly even turn robber itself. On the other hand, when the temperature is rising after a glacial

[1] Pp. 585–618.

[2] A Group of Hypotheses Bearing on Climatic Changes, Vol. V, No. 7, 1897, p. 682.

episode, dissociation is promoted, and the ocean gives forth its carbon dioxide at an increased rate, and thereby assists in accelerating the amelioration of climate.

c. Organic action. — The elimination of the vastly preponderating percentage of calcium salts in the land waters, involving a reduction from 70 per cent. in these to less than 4 per cent. in sea waters, is assigned mainly to marine life. With the calcium sulphate we do not seem to be specially concerned here except so far as indirectly it may become involved in the reactions which eliminate the calcium carbonate. It would appear obvious, however, from the fact that its ratio is reduced from about 20 per cent. in the land waters to about 3.6 per cent. in the sea waters that it suffers much secular loss. The reduction of the calcium carbonate from about 50 per cent. in the land waters to about one third of 1 per cent. in the sea waters is a fact of prime importance.

The amplest and most familiar geological observation shows that the elimination takes place mainly as normal carbonate of lime in the form of shells and skeletal parts of various marine animals, and of some plants. The gross fact of observation is the disappearance of great quantities of calcium bicarbonate from the water, and its reappearance as the secretions of animals and plants in the form of normal carbonate. Whatever may be the specific steps involved in their life economies, it seems essentially immaterial to consider here whether the animals and plants take their lime directly from the calcium carbonate, and set its surplus carbonic acid free, or whether they take it from calcium sulphate, and by using carbonic acid, derived ultimately from the waters also, convert it into carbonate, setting free the sulphuric acid to attack in turn the calcium carbonate of the sea, and thus by circuitous process free its carbonic acid, or whether the procedure follows any other indirect course; for the final result, when balanced all around, seems to be essentially the same. It may even trench on the organic cycle without essentially changing the final result. The important thing to be observed is that the process is dependent upon sea life, and varies with its

activity. There is no free supply of any competent discharging agency independent of sea life.

Variations of lime-secretion by sea life.—The amount of lime-secreting sea life is greatly influenced by the temperature of the sea and by favorable habitat. Lime-secreting sea life, both plant and animal, is greatly favored by high temperature and reduced by low. In support of this the following statements from the Challenger Report[1] and other sources may be offered, in which I have italicized the significant parts:

Species of algæ which secrete carbonate of lime are abundant in the *shallow waters* of the ocean. In the *tropical regions* especially there are massive species of *Lithothamnion, Lithophyllum, Halimeda* and other genera that make up a large part of some coral reefs and of the surrounding coral sands and muds. *Two hundred fathoms* is probably the extreme limit at which any of these organisms live in the ocean.

Rhabdospheres are especially developed in *equatorial* and *tropical regions,* and are *rarely* met with in regions where the temperature of the surface water falls below 65° F. (18.3° C.). Coccospheres, while abundant in tropical waters, are found further north and south than the Rhabdospheres; they are present even where the temperature on the surface is as *low as 45° F.,* (7.2 C.); indeed, Coccospheres attain their greatest development in *temperate regions.* These organisms are absent or *rare in coast waters* affected by rivers; they especially flourish in the pelagic currents of the open ocean. . . . In *Arctic and Antarctic waters* Coccospheres and Rhabdospheres are replaced by similar minute algæ *which do not, however, secrete rods and disks of carbonate of lime on their outer surfaces.*

Rhabdoliths and Coccoliths—the broken down parts of Rhabdospheres and Coccospheres—play a most important part in all deep-sea deposits, *with the exception of those laid down in polar and subpolar regions.*

Of all the organic remains met with in marine deposits, by far *the most frequent are the shells of Foraminifera;* it may be safely said that these organisms or their fragments are present in every average sample of marine mud, clay, ooze or sand. . . . *Nearly all the species are confined to tropical and subtropical waters; they gradually disappear from the surface-nets as the polar regions are approached,* the dwarfed forms *Globigerina pachyderma* and *Globigerina dutertrei,* being the only species met with in Arctic and Antarctic waters. . . . *In the calcareous oozes from tropical regions, the shells of all the species inhabiting the surface waters are observed in enormous abundance, but these same species are never met with in deposits from polar regions.* . . .

[1] Challenger Report, Deep Sea Deposits, pp. 257, 258–261, 263, 31 and 266.

There are not more than twenty or twenty-two species of pelagic Foraminifera, yet so numerous are the individuals of the species that they usually make up over 90 per cent. of the carbonate of lime present in the calcareous oozes of the abysmal regions of the ocean. . . .

The bottom-loving Foraminifera—those belonging to the Benthos—*are more abundant in the shallow water*, than in the deep-sea deposits, and occasionally a single species may occur in such abundance in shallow depths in some regions as to make up the greater part of a deposit. . . .

The presence of large numbers of Pteropod and Heteropod shells indicates tropical or subtropical regions, and relatively shallow depths. Abundance of the shells of pelagic Forminifera indicates the same regions, but when found without the shells of pelagic mollusks they indicate a greater depth than when these latter are present. . . . . The presence or absence, and the size of Rhabdoliths, Coccoliths and Coccospheres *give important indications as to latitude and depth*—the first predominating in tropical regions, the two latter being better developed in temperate regions, and *all disappear from the deposits as the polar waters are approached.*

"A large number of these pelagic mollusks (Pteropod and Heteropod) *secrete carbonate of lime shells, and this is especially the case in tropical waters.* In *polar* regions the place of the shelled species is taken, with the exception of one or two small species of Limacina, by a *shell-less species.* The shells of the tropical species make up a large part of some tropical and subtropical deposits from moderate depths, in which there is a relatively small quantity of land débris. *Like the pelagic Foraminifera these pelagic* Mollusca attain their greatest development in the warm oceanic currents, *and diminish both in the number of species and the size and mass of the shells as the colder currents of the polar regions are approached.*

Reef-forming corals are confined to waters which, through even the coldest month, have *a mean temperature not below 68° F.* Under the equator the surface waters in the hotter part of the ocean have the temperature of 85° F. in the Pacific, and 83° F. in the Atlantic. The range from 68° to 85° is, therefore, not too great for reef-making species.[1]

An isothermal line crossing the ocean where this winter temperature of the sea is experienced, one north of the equator, and another south, bending in its course toward or from the equator, wherever the marine currents change its position, will include all the growing reefs of the world; and the area of waters may be properly called the *coral-reef seas.* . . .

Over the sea thus limited coral reefs grow luxuriantly, yet in greatest profusion and widest variety through its hottest portions.[1]

I have found no specific statements relative to the dependence of common mollusks on temperature, but the enumeration of the

[1] DANA: Corals and Coralline Islands, p. 83.

species in different latitudes clearly indicates that they are less abundant in the arctic provinces than in the tropical, from which it may perhaps be safely inferred that the lime-secreting function of the mollusks is increased by warm temperature.

In the foregoing quotations references are made to the preference of certain forms for shallow waters. The great preponderance of lime-secreting species on the shoal areas — 100 fathoms or less — is too familiar to need emphasis.

In other articles[1] I have endeavored to show that there were certain stages in the earth's history when the seas were extended widely over the continental platforms, affording conditions extremely favorable to the multiplication of lime-secreting shallow-water life. I endeavored to connect these, on an observational basis, with the great limestone-producing epochs of geological history and to show that these were correlated with genial climates over high and low latitudes alike. On the other hand, I endeavored to show that there were other periods during which the land area was increased and the sea restricted, resulting in a great reduction of this normal habitat of the chief lime-secreting forms of life. I endeavored to show that so far as the lime-secreting life is concerned, the freeing of carbonic acid was promoted during periods of extended seas and that it was retarded during periods of extended land. This holds good when considered simply from the standpoint of available area, but it becomes still more true if, as this hypothesis maintains, the extension of sea-area was correlated with favorable temperature, while the restriction of sea-area was correlated with adverse temperature. The only pelagic life that enters much into the problem is that which occupied the superficial waters of the open ocean. The area of this increased and diminished concurrently with the extension and contraction of the sea.

[1] A Systematic Source of Evolution of Provincial Faunas, Jour. Geol., Vol. VI, No. 6, pp. 597–608.

The Influence of Great Epochs of Limestone Formation upon the Constitution of the Atmosphere, Jour. Geol., Vol. VI, No. 6, pp. 609–621.

THE FORMATION OF ORGANIC COMPOUNDS AS AN AGENCY OF ENRICHMENT AND DEPLETION

The familiar fact that plants produce complex carbon compounds at the expense of the carbonic acid of the air, and that animals, aided by plants, by combustion, and by decay, decompose these compounds, and return a portion to the air as carbonic acid need not be dwelt upon. These reciprocal processes constitute a cycle which, in so far as it is mutually compensatory, affects the constitution of the atmosphere only in temporarily locking up carbon in the transient organic matter. The cycle, however, is not complete at any time, and has fallen far short of being complete at certain times. A portion of the carbon compounds are not reconverted into carbonic acid, and this residuum has been sealed up in the strata, and represents so much of depletion of the atmosphere. When this residuum was large there was a hastening of the process of robbing the atmosphere. When it was small it put less tax upon the agencies of supply. In its concrete application, the hypothesis recognizes one notable period of residual accumulation, the Coal Measures. Subordinately it recognizes others, as the Huronian and the late Cretaceous. Perhaps the Coal Measure period is the only one in which the excess of carbon composition over decomposition was so great as to seriously influence the constitution of the atmosphere, considered by itself alone, though this is open to question. A computation of the carbonic acid locked up in coal and similar carbonaceous deposits compared with that locked up in the limestones shows that the former is greatly inferior to the latter, from which it is inferred that the organic factor has been much the less influential in producing variations of atmospheric constitution, *per se*, than through its relations to the carbonates.

Respecting the organic cycle itself, it is obvious that when the sum total of vegetable and animal life increases, the amount of carbonic acid locked up in the living organisms is increased, and *vice versa*. The total mass of all the vegetable and animal living matter on the earth is some small fraction of the total

amount of free carbon dioxide. It does not seem possible now to arrive at any closely approximate estimate of this ratio. Johnson[1] expresses the belief that the growth of plants would exhaust the carbonic acid of the atmosphere in 100 years if there was no return. The average length of time during which plant products remain as living tissue is probably greater than one year, and much less than ten years, which would make the total amount of the carbonic acid so locked up a quite small per cent. of that in the air. The amount of carbon locked up in the tissue of marine life which probably was not embraced in Johnson's estimate, would somewhat notably increase the figure, but if oceanic life is considered, the free carbonic acid of the ocean must be considered also which would greatly reduce the ratio.

A study of the life of the geological periods seems to indicate that there were very notable fluctuations in the total mass of living matter. To be sure there was a reciprocal relation between the life of the land and that of the sea, so that when the latter was extended upon the continental platforms and greatly augmented, the former was contracted, but notwithstanding this it seems clear that the sum of life activity fluctuated notably during the ages. It is believed that on the whole it was greatest at the periods of sea extension and mild climates, and least at the times of disruption and climatic intensification. This factor then acted antithetically to the carbonic acid freeing previously noted, and, so far as it went, tended to offset its effects.

THE FUNCTION OF THE OCEAN AS AN ABSORBENT OF CARBON DIOXIDE

The atmosphere penetrates the ocean by simple diffusion according to the laws of gas diffusion, modified slightly by hydrostatic pressure, and this must be considered in close computations, but is too small a factor to seriously affect the larger issues.

[1] How Plants Feed, p. 47.

Absorption of carbonic acid.—Independently of this the ocean has a specific power of absorbing carbonic acid. It is important to note that this power of absorption is greatly affected by temperature, as shown by the following table of the variations for *pure* water:[1]

1	volume of	water at	0°	dissolves	1.7967	volumes of	carbon	dioxide.
1	"	"	"	" 5°	"	1.4497	"	"	"	"
1	"	"	"	" 10°	"	1.1847	"	"	"	"
1	"	"	"	" 15°	"	1.0020	"	"	"	"
1	"	"	"	" 20°	"	0.9014	"	"	"	"

The precise rates of absorption for sea water are not accurately determined, and, indeed, are determinable with difficulty because, experimentally, they are complicated with the "loose" carbonic acid of the bicarbonates which is liable to be constantly freed by dissociation. The rates appear to be something less than those that obtain in pure water. Mr. Tolman has discussed this factor in his paper already referred to.

Release of absorbed carbonic acid.—Theoretically both the carbon dioxide diffused through the ocean and that dissolved in it should be in equilibrium with that of the air. Its quantity is dependent upon the temperature of the ocean and upon the partial pressure of the carbon dioxide of the air. Whenever the temperature of the ocean is raised a portion of its dissolved carbon dioxide is given forth. Whenever the partial pressure of the carbon dioxide of the air is reduced a portion of the free carbon dioxide in the ocean diffuses forth to reëstablish the equilibrium. The tendency to equilibrium is always present, though the constant variations of temperature and partial pressure prevent its complete realization at any particular time. If there were no counteracting influence the free carbon dioxide of the ocean would act as though it were a part of the air, and as the carbonic acid of the latter was consumed, that of the former would come forth into it.

But with loss of atmospheric carbon dioxide there is a reduction of temperature, and this increases the absorptive power of

[1] Treatise on Chemistry, Vol. I. ROSCOE and SCHORLEMMER, p. 724.

the ocean, which then tends to prevent the escape of the carbonic acid. Low temperature is, therefore, antagonistic to atmospheric resupply. Mr. Tolman has attempted to ascertain the relative value of increased absorptive power and reduced partial pressure, and, though the data are insufficient for final conclusions, finds them about equal. The withdrawal of carbon dioxide from the air does not therefore call forth a proportionate amount of free carbonic acid from the sea. Indeed, it calls forth so little that the rate of atmospheric depletion is probably not appreciably retarded by it.

Summation.—Before proceeding to make special application of the hypothesis to the recognized glacial periods it may be serviceable to bring together into briefer statement the fluctuating features of atmospheric gain and loss.

1. Of the agencies of original or permanent supply, the internal group have probably fluctuated in some rude proportion to the disruption of the crust of the earth; the external group are beyond tangible treatment, but for aught that appears may be regarded as essentially uniform.

2. Of the agencies of permanent depletion, the conversion of silicates into carbonates (the chief factor) is assumed to have fluctuated essentially with the extension and restriction of the land; the formation of carbonaceous deposits fluctuated with the well-known conditions that presided over coal accumulation.

The agencies of permanent supply and of permanent loss are both regarded as rather slow in action and as being on the whole mutually compensatory, and indeed as being in some degree self-regulative since increase of supply naturally increases consumption and reduction of supply ultimately reduces the consumption; but these relations are believed to be subject to sufficient fluctuation to give a basis for pronounced climatic changes.

The sources of temporary supply and waste are much more rapid in action and apparently more intense and voluminous in results within any brief period.

1. The sources of temporary loss are: (*a*) the locking up of carbon dioxide in bicarbonates while in solution as their second

equivalent (the great factor); (*b*) the absorption of carbon dioxide in sea water; and (*c*) its consumption in forming organic matter.

The first and greatest of these is definitely connected with extension and elevation of the land, and the second is largely a sequel to it, dependent upon the temperatures it induces, while the third does not usually coöperate with these two, but rather, to the extent of its limited competency, offsets them.

2. The sources of temporary enrichment embrace: (*a*) the discharge of the second equivalent of carbon dioxide in the sea by life action (the great factor), and (*b*) by dissociation; (*c*) the diffusion into the air of carbonic acid absorbed in the sea water due to higher temperature antagonized by reduced partial pressure, and (*d*) the freeing of carbonic acid both in the air and the ocean by the decomposition of organic matter.

These sources of fluctuation are definitely correlated with the elevation and extension of the land, on the one hand, and the extension of the sea and the reduction of the land, on the other. During an extensive elevation of the land, silicates are converted into carbonates at an increased rate and the limestones and dolomites are dissolved and carried to the sea more rapidly, both processes involving an acceleration of the consumption of carbon dioxide. Correlated with this extension of the land is a reduction of the sea area attended especially by a lessening of the area of the continental shelves which are the habitat of the chief lime-secreting life, while the area available for pelagic surface life is also lessened. Reduction in the lime-secreting life retards the incidental process of freeing carbonic acid and returning it to the atmosphere. The result is a reduction of temperature which in turn increases the ability of the ocean to absorb carbon dioxide and reduces the dissociation of the second equivalent of carbon dioxide, thus further reducing the returning process and increasing the capacity of the ocean to hold carbon dioxide notwithstanding the reduction of the partial pressure in the atmosphere. The reciprocating processes are thus temporarily affected in opposite directions so as to conjoin their results.

In periods of sea extension and of land reduction (base-level periods in particular), the habitat of shallow water lime-secreting life is concurrently extended, giving to the agencies that set carbon dioxide free accelerated activity, which is further aided by the consequent rising temperature which reduces the absorptive power of the ocean and increases dissociation. At the same time, the area of the land being diminished, a low consumption of carbon dioxide both in original decomposition of the silicates and in the solution of the limestones and dolomites obtains. Thus the reciprocating agencies again conjoin, but now to increase the carbon dioxide of the air.

These are the great and essential factors. They are modified by several subordinate agencies already mentioned, but the quantitative effect of these is thought to be quite insufficient to prevent very notable fluctuations in the atmospheric constitution. As a result, it is postulated that geological history has been accentuated by an alternation of climatic episodes embracing, on the one hand, periods of mild, equable, moist climate nearly uniform for the whole globe; and on the other, periods when there were extremes of aridity and precipitation, and of heat and cold; these last denoted by deposits of salt and gypsum, of subaërial conglomerates, of red sandstones and shales, of arkose deposits, and occasionally by glaciation in low latitudes.

T. C. CHAMBERLIN.

[The continuation of this article in the next number will embrace a discussion of the application of the hypothesis to known glacial periods, and to the oscillations from glacial to interglacial epochs, together with the agencies of localization, and a suggestion regarding the superposed minor oscillations.]

THE CARBON DIOXIDE OF THE OCEAN AND ITS RELATIONS TO THE CARBON DIOXIDE OF THE ATMOSPHERE.[1]

OUTLINE.

1. Introduction.
2. Laws of dilute solutions
   1. Mass action.
   2. Dissociation.
   3. Heterogeneous equilibrium and the change in the solubility of one salt due to the presence of others.
   4. Hydrolitic dissociation.
3. Solution of gases in pure water.
   1. Class I.
   2. Class II. — Physical solubility.
   3. Carbonic acid. — Chemical solubility.
   4. Amount of gases dissolved.
4. Solution of gases in salt solutions.
   1. Class 1. Oxygen, Nitrogen, etc.
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5. The ocean salts.
   1. Amounts.
   2. Degree of dissociation.
6. The ocean gases.
   1. Oxygen, nitrogen and argon.
   2. Carbon dioxide.
      1. Simple Solution.
      2. As H_2CO_3.
      3. Modified by the ocean salts.
      4. Maximum amount held thus in the ocean under the laws of gas absorption.
      5. Ditto. As second equivalent of bicarbonate.
7. Relation of the atmospheric and oceanic CO_2.
   1. CO_2 of the bicarbonates.
   2. Dissociation of the bicarbonates.
   3. Degree of dissociation as a function of temperature and pressure.

[1] Especial thanks are due to Dr. Chamberlin, Dr. Stieglitz and Dr. Lengfeld, of the University of Chicago, for careful revision of this article and many valuable suggestions.

4. Effect of variation of pressure and temperature postulated by Dr. Arrhenius. (*a*) Upon bicarbonate in the waters of the temperate zone. (*b*) Upon bicarbonates in equatorial waters. (*c*) Upon bicarbonates in colder waters.
5. Changes in volume of the belts due to cold water advancing southward.
6. Conclusions.

THIS subject has come to have special importance on account of the investigations of Professor Arrhenius[1] and Dr. Chamberlin,[2] on the effects of the atmospheric CO_2 upon the climate of the earth. Some of the earlier important contributions on the subject are as follows:

Tyndall calculated from his experiments that the absorption of radiant heat by atmospheric CO_2 is eighty times that of the oxygen or nitrogen, and that water vapor has an absorbing capacity of ninety-two times that of oxygen or nitrogen.[3]

By repeating and extending Tyndall's experiments, Dr. Lecher and his colleague, Pretner, concluded that carbon dioxide is the only agent in absorbing the sun's heat, and maintaining the earth's temperature above that of space.[4]

Mr. J. S. Keeler criticised the above and stated that the heat is absorbed by carbon dioxide and some other agent; either water vapor or matter in suspension.[5]

Professor Röntgen showed that water vapor has a marked absorption band in the ultra red and, therefore, plays an important part in maintaining the present surface temperature of the earth.[6]

Paschen demonstrated that both these gases play important parts in the atmosphere's heat absorption, and that sometimes one, and sometimes the other is the predominant factor.[7]

[1] Phil. Mag., Vol. XLI, pp. 237–279.

[2] JOUR. GEOL., Vol. V, 1897, pp. 663–683. Also this No., pp. 545–584.

[3] Introduction of Chemical and Geological Essays, T. S. HUNT.

[4] Sitzungsberichte des Akad. der Wissenschaften d. Wien (2) Vol. LXXXII, p. 851 (2) Vol. LXXXVI, p. 52.

[5] Am. Jour. Sci. (3) Vol. XXVIII, p. 190.

[6] Poggendorf's Annalen (2) Vol. XXIII, p. 1259.

[7] Phil Mag., S. 5, Vol. XLI, No. 251, April 1896, p. 239.

The discovery that this constituent of the atmosphere is an important dynamic factor among geological agencies has led us to investigate the eighteen potential atmospheres of carbon dioxide in the ocean. This at once leads us to a consideration of the chemistry of the ocean, and here we find that the indefiniteness of our notions upon this subject is not so much due to lack of data, for that has been collected by individuals and by well equipped expeditions, as to erroneous conceptions of the relations and reactions that obtain between the several constituents of a mixed solution. Important investigations involving large outlays of time and money have been rendered nearly valueless, because they were based upon assumptions which were accepted without proof, and which are now known to be false. The importance of the first principles which govern solution and precipitation in such a solvent as water (and which have but recently been formulated) justify a review of some of them as an aid to the interpretation of the reactions taking place in that great laboratory the ocean.[1]

Mass action.[2]—It will be remembered that Berthollet in 1803 was the first to conceive of chemical reactions as governed by equilibrium, dependent both on the mass and the affinity of the constituents. The value of his discovery was not realized because he unfortunately did not believe chemical compounds to have definite compositions.

In 1864 Goldberg and Waage re-stated the law of mass action, which may be developed as follows. Let us consider any two substances, A and B uniting to form two other substances C and D.[3]

All simple reactions that have been carefully studied have been shown to be reversible, therefore, as soon as any of C and

[1] Complete discussion of the laws of dilute solution, etc., may be found in any of the up-to-date text-books on physical chemistry.

[2] W. NERNST: Theo. Chem., pp. 353-455, etc., 117-150. OSTWALD'S Outlines of Chemistry.

[3] GOLDBERG and WAAGE: Videnskabernes Selskabs Forhandlinger, 1864.

D is formed there will be a union of C and D to form A and B. This reversible reaction is expressed thus:[1]

$$A + B \rightleftharpoons C + D.$$

Let the degrees of concentration of the active masses, *i. e.*, the masses in units volume of A, B, C and D be respectively p, q, p' and q'. The unit measure of concentration is the gr. equiv. per liter. Let K be the rate of combination of unit masses of A and B, and K′ that of C and D. Now the magnitude of the reaction of A upon B is evidently $K\,p\,q$ (for the number of impacts of A upon B depends directly on their concentration) and that of C and D is $K'\,p'\,q'$. Now when equilibrium is established, the reaction of A upon B = the reaction of C upon D or $K\,p\,q = K'\,p'\,q'$ (the law of mass action).

Dissociation.— From the study of electrolysis[2] of salts, Clausius was compelled to assume that at least a small portion of the salt was dissociated into its positive and negative ions, Na Cl, for instance, into the positive ion $(\overset{+}{\mathrm{Na}})$ and the negative ion $(\overline{\mathrm{Cl}})$.

Arrhenius[3] found that the osmotic pressure of a dilute solution of a salt in water, is that which it should have if a large proportion of the molecules of the salt are split into two smaller molecules (Na Cl for instance, into Na and Cl) and also that this change in osmotic pressure is a function of the electric conductivity. He was therefore compelled to conclude that practically all of the salt may be dissociated in very dilute solutions, but, in more concentrated solutions the proportion dissociated becomes smaller. It then became evident that this action is reversible and is expressed

$$\overset{+}{\mathrm{Na}} + \overline{\mathrm{Cl}} \rightleftharpoons \mathrm{Na\,Cl}.$$

[1] A simple illustration of a reversible reaction is the evaporation of water in an enclosed dish. Particles of water leave the liquid to form the superincumbent layer of water gas. As soon as any of the gas is formed it in turn gives back water particles to the liquid. Equilibrium is established and there is apparently no farther evaporation when the number of particles given off by the liquid equals the number of particles returned by the gas.

[2] Ges. Abh. (sep. papers) II, 135, 1867.

[3] ZEITS: Phys. Chem., Vol. I, pp. 631 ff.

Then, according to the law of mass action—

$$K_1 ab = K_2 c$$

where a and b are the concentrations of the ions ($\overset{+}{Na}$ and $\overset{-}{Cl}$) and c of the dissociated salt.[1]

$$\frac{a\,b}{c} = \frac{K_2}{K_1} = K \,.^{1} \qquad (2)$$

This K is called the ionization or dissociation constant, and is a constant under constant temperature and pressure, but is different for each different salt.

Salts, strong acids and bases (hydrochloric acid, sodic hydrate, etc.) are the substances most dissociated, while the weaker acids and bases (acetic acid, ferric or ammonium hydrate, etc.) are dissociated to a less degree, *i. e.*, the constant K is smaller.

It follows directly from equation (2) that the more diluted the solution the more complete is the dissociation. If the strength of the solution is such that concentration a and b are each represented by 2 and c by 4; and then the concentration of all be decreased so that a and b become 1, we find by substitution in the equation (2) that c also must become 1, and the ratio of dissociated to undissociated or *molecular* salt, is 1 : 1 instead of 1 : 2.

Heterogeneous equilibrium.—We may have some undissolved substance (C) in contact with a saturated *molecular* solution (C_1) of the same substance which is dissociated, more or less, into its ions (A and B). The concentrations are a and b for the ions, c for the undissolved (solid) salt, and c_1 for the undissociated dissolved part of C. Equilibrium being established between the solid C and the molecular solution of the solid ($C \rightleftarrows C_1$), the equation is

$$\frac{c}{c_1} = K_1 \,. \qquad (3)$$

But the concentration of a solid at given temperatures and pressures is a constant (its specific gravity) ($c = K_2$), therefore

[1] This simple formula is not strictly accurate in the case of electrolytic dissociation but is correct enough for our purpose.

$$c_1 = \frac{K_2}{K_1} = K_3 . \qquad (4)$$

Now the dissolved undissociated part of the salt dissociates into its ions

$$(C_1 \rightleftarrows A + B) \quad \text{or} \quad \frac{ab}{c_1} = K_4 \qquad (5)$$

but substituting from (4)

$$ab = K_3 K_4 = K. \qquad (6)$$

This K is called the constant of solubility, or the ion product. This is the law governing precipitation of electrolytes, and under it there are three cases.

(a) $ab > K$.
(b) $ab = K$.
(c) $ab < K$.

(a) If ab is greater than K the action goes $A + B \longrightarrow C_1$, and again $C_1 \longrightarrow C$, therefore we have precipitation.

(b) If $ab = K$, we have equilibrium, and neither precipitation nor solution takes place.

(c) If ab is less than K the action goes

$$C_1 \longrightarrow A + B \text{ and } C \longrightarrow C_1 ,$$

that is solution takes place.

Now, if we mix solutions of two or more salts, besides the undissociated salts which were present in the separate solutions in equilibrium with their respective dissociated ions, we will have in the mixture also the salts that can be formed by the union of the positive ion of each salt with the negative ion of each of the other salts. From the foregoing the following propositions are derived :

Proposition 1.—Mixed solutions of two or more salts will contain all the salts that can be made by the combination of the ions of the original salts together with the free ions.

Proposition 2.—Of all these salts that one will be precipitated first whose product of ionic concentration first exceeds its constant of solubility or ion product.

If a salt be added to a mixture of salts in solution, there is added not only the salt itself but its ions also. If one of the

salts of the original mixture have an ion in common with the new salt (as for instance Cl in Na Cl and KCl), then the product of the ionic concentration of each salt is increased. Now if, before mixing, this product for either salt nearly equaled its constant of solubility, the increase may be enough to bring about precipitation. If, for instance, to a solution of lead chloride, which is not altogether insoluble in water, is added a sufficiency of K Cl, this addition causes a precipitate of lead chloride, since the addition of the Cl ions of the potassium chloride causes the product $Pb \times Cl^2$ to be larger than K where Pb = concentration of lead ions, and Cl = concentration of chlorine ions.

If, however, the salt added has no ion in common with ions of the other salts, it will take away from the ions of all the salts to form some of all the undissociated salts that result from the combination of the two new ions with all the ions of the original salts, therefore the product of ionic concentration for all the salts is decreased, or, in other words, the solubilities of all the salts are increased. Hence,

Proposition 3.—In a mixture of salts those with a common ion increase the ionic concentration of each, aiding precipitation, and those without a common ion decrease ionic concentration of each, and retard precipitation, each increasing the solubility of the other.

Hydrolytic dissociation.—Water, which is one of the weakest of acids, is itself dissociated into hydrogen and hydroxyl ions ($H_2O \rightleftharpoons H + OH$); but this takes place to a very slight extent only. Kohlrausch found that at 18° C. for water distilled in a vacuum there is less than one gram of hydrogen ions in two million liters of water,[1] and Ostwald, Arrhenius, and Weis, and Kohlrausch[2] in later experiments (see reference below), found about one-sixth of this dissociation by other methods. Of course these free ions will react with ions of the salts in

[1] W. NERNST: Theo. Chem., pp. 658–662.

[2] F. KOHLRAUSCH and AD. KEYDWEILLER, Zeits. f. Phys. Chem., XIV, pp. 317–330.

solution to form some undissociated acid and base ($NaCl + HOH \rightleftharpoons NaOH + HCl$). But since there is such a very small amount of free dissociated ions of water and the dissociation constants of sodic and hydrochloric acid are large, this action is very slight. However, the salts of the weakest acids and bases are affected more by the same amount of dissociated water than those of the stronger ones, because, as shown by equation (2), K is smaller, therefore a larger amount of the undissociated acid, or base, exists in proportion to the ions.

Water when heated becomes more dissociated, and therefore a stronger acid, and this fact is sometimes made use of in the analytical laboratory, and is an important factor determining the composition of minerals deposited from hot solutions.

Solutions of gases in pure water.—If a gas dissolves in a substance with which it is perfectly neutral, that is, if no chemical reaction takes place between the gas and the solvent, then the amount of the gas dissolved in the liquid at a given temperature varies directly with the gaseous pressure, or partial pressure, if there be more than one gas.

Now, if any gas were absolutely neutral to the solvent, and if on solution its molecule suffered no change in constitution, we should get the same amount of heat absorbed or given off in the solution that would be absorbed or radiated by the same amount of gas brought to the density of the dissolved gas.

But upon solution in water it is found that some gases suffer a larger heat change than can be explained by any mere physical change in volume, while others have the same or nearly the same change in temperature, as that calculated upon the assumption of simple physical absorption. It has been shown that the gases with this large heat change upon solution undergo besides physical diffusion, a chemical change, more or less extensive. Therefore, gases may be arranged in two classes. The first class is composed of those gases which have but a slight reaction with water, and are sparingly soluble in that menstruum, and the other, of those which have large coefficients of solubility and which react with water to form definite compounds.

Of the former, those found in the ocean are nitrogen, oxygen, argon, etc., and of the latter, none are found in appreciable quantities, but we may take ammonia as a good example. This last unites with water to form NH_4OH which compound is known to exist as such.[1] The behavior of carbon dioxide towards water places it between these two classes. It unites with water to form H_2CO_3. This acid has never been separated as such, but doubtless exists.[2] This action does not give such a large coefficient of solubility as is characteristic of the gases of the second class.

The solution, then, of oxygen, hydrogen and argon, etc., is simple diffusion due to the attraction between the molecules of the solvent and those of the gas, while the solution of CO_2 in pure water includes (1) a diffusion of the gas molecules between water molecules and (2) a chemical reaction between the gas and water molecules to form carbonic acid.

Bunsen[3] has determined the solubility of the carbon dioxide for different temperatures as follows:

Solubility of CO_2 in H_2O, 1 vol. H_2O at t degrees and 760 mm. pressure dissolves V vols. CO_2 gas reduced to 0° C. and 760 mm pressure.

t° C.	V.	t° C.	V.	t° C.	V.
0	1.7967	7	1.3339	14	1.0321
1	1.7207	8	1.2809	15	1.0020
2	1.6481	9	1.2311	16	0.9753
3	1.5787	10	1.1847	17	0.9519
4	1.5126	11	1.1416	18	0.9318
5	1.4497	12	1.1018	19	0.9150
6	1.3901	13	1.0653	20	0.9014

In the above table the solubility is determined for pure CO_2 unmixed with other gases under 760 mm pressure. For low pressures the solution of the gas is proportional to the pressure or the partial pressure of the CO_2.

[1] PROFESSOR MALLET, Am. Chem. Jour., Vol. XIX, pp. 804–809.

[2] DAMMER, Anorg. Chem. II, 1, p. 871.

[3] BUNSEN'S Gasometry, pp. 287, 128, 152.

The atmosphere, of course, is not pure CO_2, but a mixture of gases in the following proportions: Oxygen, 20.9 vol.; nitrogen, 79.1 vol., of which 01.18 per cent. belongs to that group of gases called argon,[1] CO_2 .03 vol.

At any given temperature the amount of the atmospheric gas dissolved in pure water is the product of the amount dissolved under 760 mm pressure of the pure gas by the partial pressure of gas in the air. This holds for the carbon dioxide in spite of the chemical reaction $CO_2 + H_2O \rightleftharpoons H_2CO_3$. This may be seen as follows:

Let a, b, and c be the concentrations respectively of CO_2, H_2O, and H_2CO_3, therefore

$$\frac{ab}{c} = K_1,$$

but the water is so greatly in excess that its concentration, b, can be considered as a constant (K_2) or

$$\frac{a}{c} = \frac{K_1}{K_2} = K.$$

Therefore the amount H_2CO_3 $[c]$ varies directly with the amount CO_2 $[a]$ dissolved, and this is proportional to the partial pressure of the gas. Making the calculations from Dittmar's tables, we find that one liter of pure water at 15° C. dissolved from the atmosphere .32^{cc} of CO_2, 7.2^{cc} of oxygen, and 13.2^{cc} of argon and nitrogen.[2]

The absorption of gases in salt solutions.—The researches of J. Setchenow[3] show us that a gas dissolved in salt solution obeys the same laws as if the salt were not present, if there is no chemical reaction between the gas, the salt, and the solvent. In this case, however, the attractive power between the molecules of the solvent and the gas is partially satisfied by the salt mole-

[1] Chem. News, 72 p. 308. Comptes Rendus de l'Academie des Sciences, CXXI, p. 605.

[2] Challenger Reports, Vol. I, pp. 167-168.

[3] Ann. de Chemie: pp. 226-270.

cules. From some of his tables we find that for a solution of the strength of the oceanic brine the diminution of the solubility for gases of this class is somewhere near 20 per cent. (*loc. cit.* pp. 245-259).

If, however, there is a chemical reaction between the gas and the salt, the solubility is increased by so much. Oxygen, nitrogen, and argon do not react with the salts of the ocean, but CO_2 does. The carbonic acid dissociates into its ions, and these ions react with the ions of the salts to form small quantities of undissociated compounds. This reaction has an appreciable effect only where the original salt is formed from weak acids and bases. From Mr. Setchenow's tables[1] for Na Cl solution of the strength of the sea water we gather that this increase for CO_2 would not be over 20 per cent. of that dissolved by pure water (.3^{cc} per liter, a quantity wholly negligible).

The ocean salts.[2]—The average temperature of the surface of the ocean is about 15° C.

The proportion of the different salts in the ocean, Professor Dittmar finds to be wonderfully constant for all parts of the sea water. He gives the following analysis for the salt:

Cl	55.292%
Br	.1884
SO_3	6.410
CO_2	.152
CaO	1.676
MgO	6.200
K_2O	1.332
Na_2O	41.234
Basic O (equivalent to Hologen)	—12.493
	100

This table we have recalculated for the percentages of the ions according to modern usage, and in order to facilitate subsequent discussion, as follows:

[1] Loc. cit., p. 246.

[2] Phys. Chem. Chall. Exp., Vol. I. Narrative of the Cruise of H. M. S. Challenger, 1885; Ency. Brit. XXI, pp. 611 to 614.

(Cl)	55.292%
(Br)	.188
(SO_4)	7.692
(CO_3)	.207
(Na)	30.593
(K)	1.105
(Mg)	3.725
(Ca)	1.197
	99.999

While the average constitution of the salts remains a constant, the salinity of the ocean is variable. Averaging 327 analyses, it is found that the average amount of salt is 34.7 grams per kilogram sea water, or taking the average specific gravity of the ocean as 1.026, about 35.6 grams per liter.

Applying this to the second table, we find that the total number of grams of the different ions per liter is as follows:

(Cl)	19.68
(Br)	0.07
(SO_4)	2.74
(CO_3)	0.08
(Na)	10.89
(K)	0.4
(Mg)	1.33
(Ca)	0.43
	35.69

Dividing by the equivalent weights, we find the relative strength of the ions per liter to be as follows, where the normal solution (one which contains as many grams per liter as the equivalent weight of the substance) is taken as unity.

Relative strength per liter	
(Cl)	0.55 N. sol.
(Br)	0.0009 "
(SO_4)	0.057 "
(CO_3	0.0027 "
(Na)	0.47 "
(K)	0.01 "
(Mg)	0.112 "
(Ca)	0.022 "

Dividing the relative strength of the bivelant ions by 2, we find the relative number of ions.

Relative No. of ions	
(Cl)	5500
(Br)	9
(SO_4)	285
(CO_3)	13
(Na)	4700
(K)	100
(Mg)	560
(Ca)	110

In the light of the previous discussion, we see that there must be sixteen different salts and eight different ions in the solution, under the supposition that the salts with bivalent ions dissociate completely into their metal and acid ions, and always neglecting the subordinate elements, such as strontium, iodine, gold, etc. Since, however, in a solution as strong as the sea water, there are two reactions in the dissociation of the salts having one bivalent ion, viz.:

$$Na_2SO_4 \rightleftarrows (\overset{+}{Na}) + (\overset{+}{Na}) + (\overline{\overline{SO_4}})$$
$$Na_2SO_4 \rightleftarrows (\overset{+}{Na}) + (\overset{-}{NaSO_4})$$

there are also these extra ions, viz., ($Na\ SO_4$), of the bivalent acids and bases. Also instead of simply the salt of the radical CO_3 (normal carbonate) we have both the bicarbonate of the acid radical ($H\ CO_3$) and the acid radical itself.

From the propositions of the theory of dilute solutions it is possible to develop equations whose solutions will give the proportions of the various undissociated salts and of the free ions, but these computations would be of little value because of their complexity, and because the ocean water is too strong a solution for a numerical application of the equations developed for dilute solutions.

However, assuming that the constant K is of the same order of value for all the salts, and that the concentration of the free ions may be expressed by the relative number of ions calculated under the assumption that the salt is completely dissociated (see table p. 596), and neglecting the presence of the bicarbonate ion, we see that the relative amount of the undissociated salts will be expressed roughly by the products of the concentration of their respective radicals, and, therefore (from table p. 597) 1) $Na\ Cl$, 2) $Mg\ Cl_2$, 3) $Na\ SO_4$ exist in molecular form in greatest quantity, the rest following in about the order:

4) $CaCl_2$
5) K_2Cl
6) $MgSO_4$
7) Na_2CO_3
8) NaBr
9) $CaSO_4$
10) K_2SO_4
11) $MgCO_3$
12) $MgBr_2$
13) $CaCO_3$
14) K_2CO_2
15) $CaBr_2$
16) KBr

If we examine the following table of Kohlrausch for K Cl and apply it to all the salts of the ocean, comparing the strengths of the oceanic solutions with the strengths of the K Cl solutions given in the table, we can form an approximate idea of the proportions of the molecular or undissociated salts to their respective free ions.[1]

N.	Per cent. dissociated molecules
1.	.75
.5	.78
.1	.86
.01	.94
.001	.98
.0001	.99

Under N is the strength of the solution where the normal solution is taken as unity.

From the above table and the one on p. 597 we conclude that somewhere about 80 per cent. of the sodium chloride is dissociated into its ions. We cannot judge so well about the sodium sulphate or magnesium chloride, but they also have some considerable amount of molecular salt, possibly more than of the sodium chloride. The potassium chloride is somewhere around 90 per cent. dissociated, and the potassium bromide, the last of the series, is practically completely dissociated.

The ocean gases.—The gases found dissolved in the ocean

[1] NERNST: Theo. Chem., p. 314.

water are nitrogen, oxygen, argon, and carbon dioxide. The nitrogen, argon, and oxygen are absorbed into the ocean directly from the air. Since the ocean is very generally agitated into waves, we may suppose that the gases dissolved in the outer portion of the surface water are in direct equilibrium with those of the air. The surface waters are being saturated with gas at temperatures varying with the daily and seasonal changes. Therefore, if there is no depletion or increase of these gases due to chemical or organic agencies we may assume roughly that the ocean, on the average, contains these gases in a proportion which may be calculated from the coefficients of absorption for the average temperature of the surface of the sea, which we assume to be 15° C. Therefore, to find the average amount of nitrogen, argon, and oxygen dissolved in the ocean we must determine their respective coefficients of absorption for sea water. From the remarks on the effect of salts on the solution of gases we should expect that the salt water would dissolve a little less of the above-mentioned gases than fresh water, because (1) salts in solution decrease the solubility of gases, and (2) because none of the gases react chemically with the ocean salts.

The following table, which is taken from a larger table of Dittmar, shows that these theoretical conclusions are correct:

cc AIR DISSOLVED PER LITER.[1]

	Pure water	Sea water
−5°	.....	27.27
0°	29.54	23.78
5°	26.09	21.08
10°	23.37	18.92
15°	21.16	17.17
20°	19.33	15.72
25°	17.80	14.44
30°	16.49	13.44
35°	15.36	12.53
40°	14.37	.....
45°	13.50	.....
50°	12.73	.....

[1] Loc. cit., pp. 172 and 175.

Taking, therefore, the coefficient of absorption for sea water as given by Dittmar[1], we find that at 15° C. the sea water dissolves 5.83^{cc} of oxygen and 11.34^{cc} of nitrogen and argon, which is less than shown by the figures given on page 594 for the absortion of pure water. We find on comparing these figures with the average of the gases as found in the Challenger analyses that the amount of the nitrogen and argon is near the amount calculated for the temperature of the water at the time it was collected, as we might expect in view of the mixing, etc., it undergoes. The oxygen, however, is always low, as it is used up in the oxidation of the organic matter in the ocean. It is almost up to the calculated amount in the surface water but a very large deficit in the deeper water. We may suppose, then, that the above figure for nitrogen and argon is approximately correct, but that the oxygen figure is considerably too high.

It is evident that we have a very different case to deal with in the solution of the CO_2 in the ocean. We have already found three ways in which the gas is held in solution. (1) Simple physical absorption; (2) united with the water to form (H_2CO_3); (3) held by equilibrium reactions with the salt ions. The total that can be held in these three ways at atmospheric partial pressure of the gas and at the average temperature of 15° is about 0.3^{cc} of CO_2 per liter of sea water.

Now, under the assumption that the partial pressure of the CO_2 increases with the depth of the ocean; and that the rate of this increase obeys the same laws as the increase of atmospheric pressure with the depth of the atmosphere, and, taking the average depth of the ocean at the large figure of three miles, we find a formula developed by Professor Woodward[2] that the pressure at that depth is 4.4 that at sea level. Also assuming that *all* the ocean is at a temperature of 0° C. (instead of only the portion at great depths) we find as a maximum estimate the ocean cannot hold over 2.4^{cc} CO_2 per liter dissolved as a gas,

[1] Loc. cit., p. 139.

[2] Communicated in a letter to Dr. Chamberlin.

according to the laws of gas absorption; this it is to be noted, under the unrealizable conditions of a uniform temperature of 0° C. and an average depth of three miles. But Mr. Buchanan found that on boiling, sea water gives an average 45^{mg} or 23^{cc} CO_2 per liter, or ten times the greatest amount the ocean could hold as a gas under more favorable conditions than those of the present time. Mr. Jacobson found 90^{mg} upon distilling the water to dryness. Mr. Buchanan thought that this great excess of CO_2 over that which could remain in solution under atmospheric pressure of CO_2 must be held in some sort of loose combination with one of the salts, and he decided upon the sulphates as the retaining agent. Such a misinterpretation, of course, might be expected at that time from the imperfect knowledge of the nature of the solutions. Before determining the free CO_2, therefore, he precipitated the sulphate with barium chloride, and unfortunately he must have obtained a mixture of $Ba\,SO_4$ and $Ba\,CO_3$, so that his numerous determinations are all probably somewhat too small.

But in spite of this his analyses show that the ocean contains about eighteen times the CO_2 of the atmosphere. Now, bearing in mind Professor Arrhenius' statement, "that to lower the temperature of the temperate region 5°, and bring on glaciation, the CO_2 of the atmosphere needs to be diminished to from 62 per cent. to 55 per cent. of its present value,"[1] the following questions suggest themselves:

1. How is the excess of the CO_2 found in the ocean at the present time held in solution?

2. Is it in equilibrium with that of the air?

3. If so, what proportion of the ocean gas will be brought out into the air by a diminution of the partial pressure of the CO_2 to an amount from 62 per cent. to 55 per cent. of its present value?

4. How much will the consequent fall of temperature increase the ocean's capacity for CO_2?

5. What is the relation between these two?

[1] Loc. cit., pp. 237–279.

In its immediate action, the ocean certainly has a moderating effect upon the temperature of the land. The great amount of heat necessary to raise the temperature of the water one degree, together with its vast evaporating surface, distributes the warmth received during the day over the night, much of the excess of the heat of summer throughout the winter, and the great downpour of radiant energy upon the tropics over the temperate and frigid zones. The question then arises: In the greater cycles of the variation of the earth's climate (whether dependent directly or only in part upon the fluctuations of the carbon dioxide content of the atmosphere) does the ocean still play the beneficent rôle of protector against the advances of the greater winters, furnishing the atmosphere some of its enormous supply of CO_2 as a blanket against the cold? Or, does the increasing cold cause the ocean, like a selfish monster, to keep a more grasping hold on the precious gas as the need of it becomes more imperative?

1. Besides the CO_2 which may be absorbed by the ocean from the air, it receives the gas (1) from the respiration of aquatic animals (2) from the decomposition of organic matter (3) from the interior of the earth through springs, etc., and (4) from the bicarbonates brought in by the rivers.

We find from analyses of the water of the principal rivers[1] of Europe, that about 60 per cent. of the entire mineral content of the river water is calcium carbonate dissolved as calcium bicarbonate. This calcium bicarbonate then is the great source of the extra carbon dioxide of the ocean. When this bicarbonate mixes with the ocean it is no longer strictly speaking, calcium bicarbonate, but mostly bicarbonate ions in equilibrium with small amounts of sodium, magnesium, calcium and potassium bicarbonates.

2. The various bicarbonates have been subject to numerous investigations since the researches of H. Rose[2] in 1835. These contributions show that sodium, potassium, ammonium, and

[1] BISCHOF, Chemical and Physical Geology, Vol. I, pp. 76, 77.

[2] Journal für Praktische Chemie, Neue Folge 10, 1879, pp. 417–444. Zeits. für Anorg. Chemie., Vol. XVII, pp. 170–204.

magnesium bicarbonates, partially dissociate at ordinary temperatures into the normal carbonate, giving out CO_2. Treadwell and Reuter have shown in the latest and most complete research on the subject (see reference above) that when calcium carbonate is dissolved under different partial pressures of CO_2, that the proportion of calcium to carbon dioxide, indicates that practically a pure bicarbonate, and not a mixture of bicarbonate and carbonate, is present in the solution.

The difference between the sodium, magnesium, etc., bicarbonates on the one hand, and the calcium bicarbonate on the other is seen from the following: (1) For the dissociation of magnesium bicarbonate we have in a saturated solution,

$$Mg(HCO_3)_2 \rightleftharpoons MgCO_3 + H_2CO_3 .$$

We have seen that the H_2CO_3 is directly in equilibrium with the CO_2 in the air; therefore at a given temperature, the degree of dissociation depends upon the partial pressure of the CO_2 in air. With variations of temperature, the colder the water, the larger is the portion of bicarbonate present, and therefore, the larger is the proportion of carbon dioxide in the ocean to that in the air. (2) For calcium bicarbonate we have:

$$Ca(HCO_3)_2 \rightleftharpoons CaCO_3 + H_2CO_3 .$$

But $CaCO_3$ is very slightly soluble, and therefore practically a constant for a *saturated* solution. Therefore, we do not have a mixture of bicarbonate and appreciable quantities of the carbonate, but the salt in solution is nearly all bicarbonate, and by lessening the partial pressure of the CO_2, $CaCO_3$ is precipitated from the saturated solution and the bicarbonate decreases. However, this difference between $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ which Treadwell has emphasized, only holds for saturated solutions. It is evident that for an under-saturated solution of $Ca(HCO_3)_2$ we may have a larger proportion of normal carbonate than in the saturated solution and still no precipitation. Also, in ocean water (see p. 591), the numerous different salts tend to increase the solubility of the normal

carbonate, and allow perhaps a somewhat greater dissociation of the bicarbonate into carbonate. The bicarbonate in the ocean is, as shown above, not calcium bicarbonate, but bicarbonate of all the bases in solution, so that Treadwell and Reuter's investigations upon *pure* calcium bicarbonate in *saturated solution* cannot be taken to prove that the bicarbonates of the unsaturated sea water cannot be dissociated.

As direct evidence that the ocean is not saturated with calcium acid carbonate, we find (1) of the many hundred bottles of the Challenger's samples of sea water, from all depths and collected at all temperatures, kept several years, only one or two showed deposit of lime.[1] (2) Seashells from the bottom of the Pacific show corrosion and resolution.[2] Pteropod shells and foraminifera tests are slowly dissolved as they sink. The Pteropod shells are not found below fifteen hundred fathoms, and two thousand eight hundred fathoms is the limit for the globigerina ooze.[3] (3) Thoulet found by actual experiment that sea water will dissolve calcium carbonate from shells, corals, etc.[4] (4) Usiglio, studying the evaporation of the Mediterranean water at Cette, found that no precipitate was formed until the specific gravity of the sea water increased from 1.02, the specific gravity of the unevaporated water, to 1.0503 when the first precipitation begins, composed largely of calcium carbonate with ferric oxide.[5]

DEGREE OF BICARBONATE DISSOCIATION.

From twenty-seven analyses by Jacobson, we find an average of 91.4^{mg} per liter of free CO_2, and 120^{mg} CO_2 in the normal carbonate, or the bicarbonate is so dissociated that 25 per cent. of its second equivalent of CO_2 is lacking.[6]

[1] Loc. cit., p. 221.

[2] JOUR. GEOL., Vol. I, p. 504.

[3] Loc. cit., p. 221.

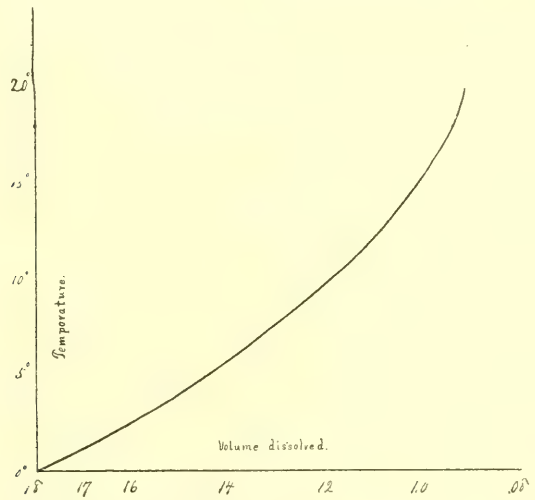
[4] Comptes Rendus, Vol. CVIII, p. 753.

[5] Encyl. Brit., Vol. XXI, p. 229.

[6] Uber die Luft des Meerwassers Ann. der Chemie und Pharm., Vol. CLXVII (1873), pp. 1–38.

From several hundred determinations of Buchanan, we strike an average of 45^{mg} free CO_2 per liter, to 53.4^{mg} CO_2 per liter of the *first* equivalent, *i. e.*, only 84 per cent. of the second equivalent is found in the ocean. Mr. Jacobson's analyses show a larger per cent. of the carbonates than were found in the Challenger's samples, which might be expected, as Jacobson's were collected only from the North Sea into which flow the great lime-bearing rivers of northwestern Europe.

To prove positively that the ocean bicarbonate dissociates into carbonate and free CO_2, Professor Ditmar shook in the air



FIGS. 1 and 2 represent respectively the effect of temperature on the solubility of CO_2 in pure water, and upon the dissociation of Na H CO_3.

FIG. 1 is taken from table on page 593 and under 760 mm pressure CO_2. The temperature is recorded on the ordinate, and on the abscissa are the volumes of CO_2 absorbed, compared with the volume of water in which it is dissolved.

a sample of sea water, that had an excess of CO_2, and found that CO_2 was given off, and that the ratio of the two equivalents was 100:84 at 13° C., exactly the same, it happens, as we found from averaging Buchanan's analysis. Therefore we may consider it as certain that the largest part of free CO_2 in the

ocean is held as the second equivalent of bicarbonate, and that this is held in equilibrium with the gas in the air.

We know then from the above that the dissociation of the bicarbonate is a function of the temperature, and also of the partial pressure of the superincumbent CO_2. The solubility of CO_2 as a gas not attached to form bicarbonate, is also a function of temperature and pressure, but that these functions are not the same, may be seen from an inspection of the

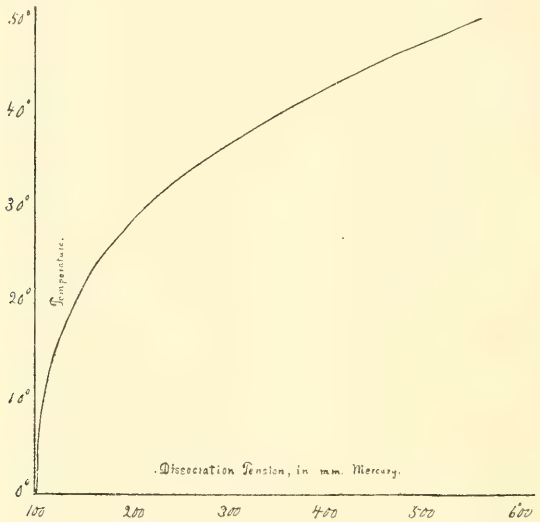


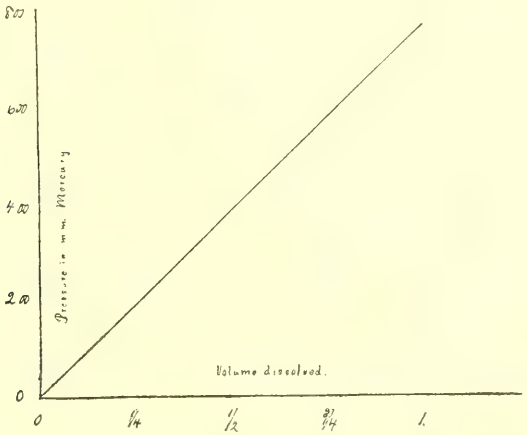
FIG. 2 is plotted from Dr. Dibbett's tables.[1] On the ordinate are the temperatures and on the abscissa the increase of the dissociation of the Na H CO_3 in mm of mercury which represents the loss of the second equivalent of CO_2 from the solution.

accompanying curves. Professor Ditmar has experimented upon the effect of changes of partial pressure and temperature upon the CO_2 in the ocean. This includes both the effect upon the portion simply dissolved and that as second equivalent of bicarbonate. We shall discuss these results under Professor Arrhenius' hypothesis of lowering the surface temperature to

[1] Ueber die Loslichkeit und die Dissociation des sauren kohlens Kaliumes, Natriurns und Ammomiums, Journal für praktische Chemie, neue Folge 10, 1879, pp. 417–444.

an average of 10° C., and the diminution of the partial pressure he has postulated as sufficient to cause this drop in temperature.

We find from Professor Ditmar's investigation (see tables and figures, pp. 609 and 610) that as the waters of the ocean become warmer, the effect of a change in the partial pressure of atmospheric CO_2 upon the bicarbonate dissociation becomes greater, while near zero a change in partial pressure has no effect on the dissociation of the bicarbonates of the ocean. On the



FIGS. 3 and 4 show the relation between the partial pressure of CO_2 and its solubility in pure water on the one hand and the solubility of Ca H_2 $(CO_3)_2$ on the other.

FIG. 3 represents the simple law of gas absorption that the amount dissolved is directly proportional to the partial pressure. The pressure is plotted on the ordinates in mm of mercury and the volume of gas absorbed on the abscissa.

other hand, the effect of any postulated fall in temperature, causing the bicarbonates to take up CO_2, is the greatest at the temperature just above 0°, and becomes less for higher temperatures. So that a fall in temperature of the colder waters of the ocean is correlated with the greatest absorption of CO_2, and without the counteracting effect of decreasing partial pressure. In equatorial waters, however, the fall in temperature does not

produce so great an increase in the absorption of the CO_2, and the effect of decreasing tension of atmospheric CO_2 approaches a maximum.

These facts, therefore, naturally divide the discussion into three parts. Under Professor Arrhenius' postulates as to change in temperature and pressure, we shall discuss the relative effect of these two opposing factors in the temperate waters whose temperature is the average surface temperature of the ocean, viz., 15° C. (2) Ditto for the tropical waters whose temperature is above 15° C. (3) Ditto for the polar waters whose temperature is below this.

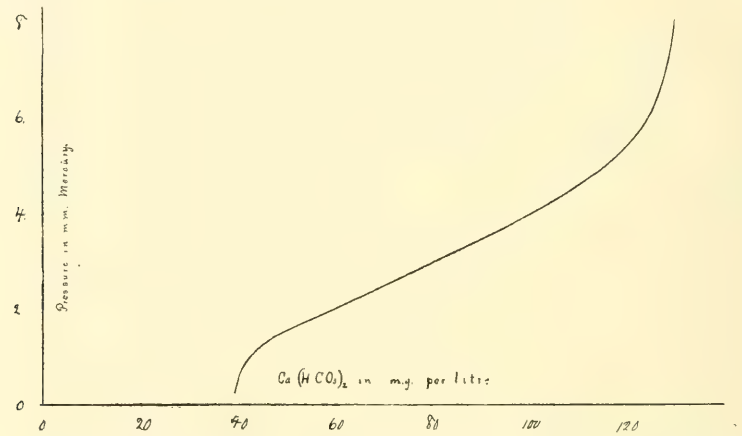


FIG. 4 is from Treadwell's and Reuter's dissertation (see reference, p. 603). The partial pressure is represented on the ordinate in mm of mercury and the amount of calcium bicarbonate dissolved in m. g. in the abscissa. At atmospheric pressure 15° C. the amount dissolved in pure water at saturation is 38.5 *m. g.* per liter, which is much less than the amount of bicarbonate in the sea, as we might expect from the previous discussion.

The only experiments which have been made upon sea water (and so under the actual conditions of the problem) are represented in Fig. 5. Professor Ditmar took a special sample of deep ocean water which was so charged with CO_2 as to have its bicarbonate fully saturated with CO_2. This he shook violently in a bottle constantly renewing the air until there was no more

loss of CO_2 from the water and no more gain in the air above the water. The carbon dioxide remaining in the water was thus determined, and the degree of the bicarbonate dissociation calculated. This was repeated for various temperatures.

The table is as follows :[1]

t	N	Pure Air (n_0)	Ordinary Air (n_1)
2	200	1.90	
2	200	2.04	
2	52		2.06
10	200	1.70	
13	50		1.84
15	100	1.63	
15	200	1.50	
20	200	1.42	
25	53	1.53	
32	52	1.33	
32	52		1.89
32	150		1.82

t=equals temperature. N=number of times air was renewed until loss of CO_2 from water ceased. n_0=ratio of first to the second equivalent of CO_2 in bicarbonate when shaken in air free from CO_2, where 2.00 represents fully saturated bicarbonate and 1.00 simply the normal carbonate. n_1=the same for ordinary air.

These experimental data do not permit the drawing of any very accurate conclusions. Professor Ditmar states that these are only preliminary, and has promised us a completion of this work, which we await with impatience. However, we must needs use what we have, and referring to curve 5, we see that at 15° the ocean will contain about 83 per cent. of the total second equivalent of CO_2, and at 10°, about 88 per cent. of it, or an increase of 5 per cent. of the second equivalent which is represented by the line *a–b* in figure. For pure air artificially freed of CO_2 at 10° the dissociation goes through 70 per cent. but Professor Arrhenius does not postulate a complete removal

[1] Enyc. Brit., Vol. XXI, p. 612.

of CO_2 from the air, but a diminution of from 62 per cent. to 55 per cent. of the present partial pressure of the gas, and this decrease in dissociation caused by the decrease of the partial

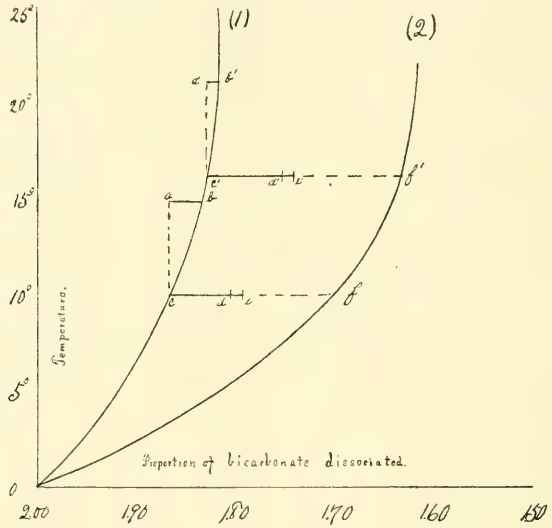


FIG. 5 is plotted from Professor Ditmar's table on page 609. The figures in the table are not very constant, but we have taken those that seem to correspond best with each other. On the ordinate are the temperatures, and on the abscissa the dissociation of the ocean bicarbonate, 2.00 representing fully saturated bicarbonate and 1.00 normal carbonate, the partial pressure of CO_2 in the curve (1) is that of the atmosphere as it is at the present time and for curve (2) there is 0 pressure of that gas. The two curves have been plotted arbitrarily to cut a 0°, but Professor Ditmar shows that there is probably no dissociation at 2° to 3° above zero.

The line *cf* connects the two curves at 10° (the temperature of the temperate regions Dr. Arrhenius postulates to develop a glacial period) and the points *d* and *e* show the bicarbonate dissociation at a partial pressure of CO_2 reduced respectively to 62 and 55 per cent. of its present value. *a b* represents the decrease of the dissociation of the bicarbonates due to fall of temperature from 15° to 10°) and *c d* and *c e* the increase of the dissociation due to a decrease of 62 per cent. and of 55 per cent. of the present value of the partial pressure of CO_2 in the air. *a' b'* and *c' d'* and *c' e'* represent the same factors for a decrease of temperature from 21° to 16° and the same decrease as postulated above in the partial pressure of the CO_2.

pressure of the gas is represented by lines *c–d* and *c–e*; so that the dissociation will be between the two, that is, viz., from 76 per cent. to 81 per cent., *i. e.*, these data show that the falling

temperature counteracts within 2 per cent. to 4 per cent. of the total CO_2 as second equivalent, the effect of the decrease in the partial pressure.

These estimates are of course founded on too small an experimental basis, and the data themselves show too great disagreements to conclude that the decrease of the dissociation due to the falling temperature, counteracts exactly within 2 per cent. to 4 per cent. of the second equivalent of CO_2, the increase due to the diminishing partial pressure ; but we may conclude *that they are probably of the same order of magnitude*, or that *a–b* is comparable in length with *c–d* or *c–e*.

All this however, is under the proposition of Professor Arrhenius, that a 5° lowering of the average climate of the *temperate* regions will bring on glaciation. We have still to consider the effect of the waters of the equatorial region on the one hand, and those of the higher latitudes on the other.

The average temperatures of the ocean waters at the surf line between 45° north and south latitudes, are as follows :[1]

For the belt between 15° north latitude, and 15° south latitude, 26 degrees centigrade.

For the belts between 15°–30° north latitude, and 15°–30° south latitude, 21 degrees centigrade.

For the belts between 30°–45° north latitude, and 30°–45° south latitude, 17 degrees centigrade.

The average temperature between 45° north latitude and 45° south latitude, at the depth of 1500 fathoms is between 2°–3° centigrade.

Professor Ditmar has found that at temperatures between 18°–21° C. that the dissociation tension of the bicarbonates of the sea water is five ten-thousandths of an atmosphere. On the other hand, at temperatures near zero, the dissociation does not take place, and the tension of course becomes nil. (See table above.)

The partial pressure of the CO_2 in the atmosphere at the present time is about three ten-thousandths. Therefore, he con-

[1]Compiled from tables Challenger's Rep., Vol. I, Table VI, at end of volume.

cludes that the warmer portions of the ocean are constantly supplying CO_2 to the atmosphere, and the colder portions are always removing it.[1]

The falling temperature which causes the glacial period must affect the temperature of the surface of the equatorial water, especially after an ice advance is inaugurated, but how much we cannot estimate. Taking the average surface temperature of these waters as 21°, and postulating the same fall of temperature as for the temperate waters, we see that the line $a' b'$ repsenting the decreasing dissociation due to the falling temperature, is much shorter than the line $c' d'$ or $c' e'$, representing the increase in the dissociation caused by the decreasing partial pressure of CO_2. However, the data upon which this part of the curve is based are much more conflicting and less satisfactory than those represented by the curve at 10°. But we may conclude that in the equatorial region the diminishing partial pressure has a greater effect than the postulated fall of temperature. But, with the increasing cold, the heated areas which can give off carbonic acid to the air are greatly diminished, especially after the glaciation has commenced, and this acts directly counter to the diminishing partial pressure.

In the northern seas whose surface temperature is near zero, each molecule of carbonate has the power to take up carbonic acid until it becomes a fully saturated bicarbonate. Just how much increase this area will undergo on an approach of a glacial period we cannot well estimate, but perhaps we can get a fair idea of it by comparing the area of the ocean contained within the circle of latitude which bounds the northernmost point of Greenland glaciation with that contained within the circle bounding the southern limit of Pleistocene glaciation. The ratio between these two areas is 2 : 5. These figures may not even approximately represent the real increase of the cold waters during glacial times, but they emphasize the fact of an actual and great increase in the amount of these waters.

The table on p. 609, as stated before, shows that at low tem-

[1]Chal. Rep., Vol. I, pp. 212, 213.

peratures the decrease in the partial pressure of the atmospheric CO_2 has practically no dissociating effect upon the bicarbonates of the ocean, and therefore that the large increase in the capacity for absorbing CO_2 is not affected by the diminishing partial pressure.

To sum up then: (1) the increase in the ocean's capacity for CO_2 at low temperatures, and (2) the invasions of the polar waters toward the equator, both tend directly to rob the atmosphere of CO_2, unaffected by any diminishing partial pressure of that gas. In the temperate waters the effects of increasing cold and decreasing partial pressure seem to be fairly evenly balanced, with a possible advantage for the diminishing partial pressure, against which must be reckoned a decrease in the amount of these waters. In the equatorial waters the effect of the decreasing partial pressure exceeds that of falling temperature, counterbalanced by a large decrease in the amount of these waters.

This division of the ocean with three belts shows us clearly the factors in the problem, but does not give us means by which to find the relative values of these factors—that is, to show us whether or not the intensifying factors, such as falling temperature and increasing areas of polar waters and decreasing areas of equatorial waters, more than counteract the effect of the diminishing partial pressure of the CO_2 over the temperate and equatorial waters.

In order to get some rough comparative value of these factors without pretending to get any accurate quantitative estimate of their actual value, we have tried to estimate the volume of the ocean water, whose temperature is reduced from 7° to 2°, from 12° to 7° and from temperatures above 12°, etc., and to calculate the amount of CO_2 these volumes of the waters can absorb on account of their lower temperature on the one hand and to estimate the greatest amount of CO_2 that might be freed from the tropical waters compatible with their restricted volumes on the other hand.

As shown in Fig. 6, we have assumed that the polar waters

(viz. those with temperature of 2°–3° C.) will advance southward at least as far as the southernmost limit of the ice-sheet. Therefore, we have started the line *a b* at 60° N. and S. latitude (the latitude of the southern Greenland glaciation) and the line *e h* at 37° (the latitude of the southernmost Pleistocene glaciation in North America). With this postulated southern advance of the cold waters, there must also have been a rise of these cold waters toward the surface. The amount of this rise is undeterminable at present. But since we have used Dr. Arrhenius' estimate of a drop of 5° in the temperature of the surface waters, we may assume the same fall of temperature for the body of the ocean. A given fall in temperature of the surface water must

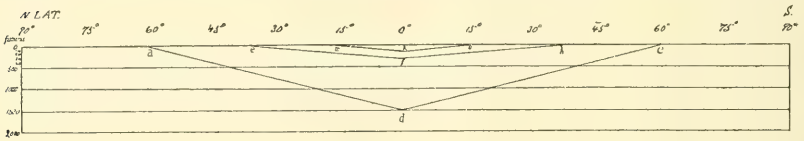


FIG. 6.—Section of ocean from north to south pole. Ocean taken at average depth of 2000 fathoms. Portion below 1500 fathoms has temperature below 2° to 3° C.

Line *a d c* incloses section of ocean whose temperature is now above 2° to 3°. Line *e f h* limits the equatorial and upward migration of the polar waters during maximum Pleistocene glaciation, when the ice reached the latitude 37° N.

Line *m k n* ditto for waters with Pleistocene temperature of 2° to 7°.

Above line *m k n* ditto for water of higher temperature.

take a very long time to communicate itself throughout the body of the ocean, but the larger the period during which the surface waters maintain their low temperature the more completely does the body of the ocean lose its extra heat.

At 1500 fathoms the temperature of the temperate and equatorial waters is 2°–3° C. above zero; therefore, the maximum depth which the line *a–c* reaches is placed at *d*. At 300 fathoms the warm waters have a temperature of about 7°.[1] Therefore, we place here *f* on the line *e f h*, designating the maximum advance upwards of the polar waters.

Point *k* on *m-k-n* is 150 fathoms below the surface and at that

[1] All temperatures calculated from tables of temperatures, given in Vol. I of the Challenger Reports.

depth the equatorial waters have average temperature of 12°. Therefore, this will be the limit of the waters of the belt that had temperatures of 2° to 7° during maximum glaciation. Above *K* are the waters which now have temperatures above 12°, and during glaciation temperatures above 7°.

To get a correct conception of this section of the ocean waters from pole to pole, we must multiply the length given here by 550.

The portion of the ocean below 1500 fathoms is already down to the limiting temperature; therefore, its carbon dioxide content is not subject to fluctuations. This leaves out of the 18 atmospheres of "free" CO_2 about 13 atmospheres above the 1500 fathom line.

The volume of these waters is divided as follows:

90° to 60° N. and S. latitudes, - - -	11%
60° to 37° " " - - -	24
37° to 6° " " - - -	65

Now, the volume of water included between *a d c* and *e f h* is considerably over one half that above the 1500-fathom line, or it holds about seven atmospheres CO_2, and a change of temperature from 7° to 2° represents a change in the dissociation of the bicarbonates from 1.9 to 2.00 (see Fig. 5, p. 610), or more than a 10 per cent. increase in the "free" CO_2. Therefore, this advance of the cold waters upward and toward the equator represents an increased capacity of the ocean for CO_2, equal to about seven tenths that of the present atmosphere.

The waters above *m k n* represent those which now have a temperature above 12° C. (we neglect the warm surface waters now spread far poleward by the warm currents), and it is in the warmer of these waters that the diminishing partial pressure of the CO_2 may cause a loss of CO_2 from the ocean.

Now this volume represented by *m k n* is considerably less than 2 per cent. of the volume above the 1500 fathoms line, so that for a limiting case if *all* the second equivalent were lost in these waters, instead of only at most a small portion of it, it would amount to less than one third that gained by the advance of the

cold waters, and in the actual case probably not more than one fortieth of the same.

Admitting all the inaccuracies of our assumption, still it seems to be clear that with falling temperature *the ocean will dissolve CO_2 from the air.*

The effect becomes more pronounced as the glaciers become more extensive and thus directly chill the ocean waters. We offer this as the most important accumulative factor causing the great extent of the glacial invasion, acting until overcome by a number of opposite agencies.

Dr. Chamberlin[1] has shown that the amount of CO_2 in the atmosphere at any one time, and therefore the climate of the earth at that time, depends upon the value of the ratio of the supply of the gas to its depletion. Besides the continuous supply that the atmosphere receives from the interior of the earth and from planetary space and the continuous depletion due to the formation of the carbonates in place of the igneous alkali earth silicates, there are variations in the ratio of supply to depletion dependent upon the attitude of the land and water.

A large exposure of land surface is correlated with a rapid solution of calcium and magnesium carbonates, and this solution is accompanied by a change from the normal carbonate to the bicarbonate form, and therefore represents a loss of CO_2 from the atmosphere.

On the other hand the formation of the normal carbonate by lime-secreting animals causes a direct liberation of the second equivalent of the bicarbonate. Therefore extensive oceans and abundant marine life are correlated with warm climate, and restricted seas and elevated land cause loss of CO_2 and colder climate.

Now, to investigate the rôle the ocean plays in this conflict:

1. The chief agencies in the *removal* of the carbon dioxide from the air are (a) the formation of the carbonates from the silicates; (b) the solution of the carbonates as bicarbonates. These are dependent upon the attitude of the land and water,

[1] See PROFESSOR T. C. CHAMBERLIN, JOUR. GEOL., Vol. V, p. 682.

the elevated land being accompanied by rapid disintegration and erosion. The increasing cold only slightly affects this process (a′) by the decrease in vegetation; (b′) by the slight decrease in chemical activity of the CO_2; (c′) by the freezing of the ground, preventing free percolation of the underground water, etc. But it aids disintegration by frost action, etc. (c) The polar seas constantly absorb CO_2 from the atmosphere. The increasing cold, with the increasing volume of cold waters, therefore *directly robs* the atmosphere of the CO_2. This process is not so marked in the warmer waters, because of the counteracting effect of the postulated diminishing partial pressure of CO_2.

2. The *supply of* CO_2, outside of that of plutonic and extraterrestrial origin comes (a) from the dissociation of bicarbonates in equatorial waters. The decreasing partial pressure aids this and the restricted area of warm water counteracts it. (b) The second equivalent of bicarbonate freed by lime-producing animals. The fall of temperature directly affects this most important source of supply, as it is well known that a fall of a few degrees in the ocean water would wipe out whole genera of test-producing animals.

To sum up, then: Accepting Dr. Chamberlin's proposition that the advance of a cold period is primarily dependent upon the altitude of land and water, the effect of the ocean is both to remove the atmospheric carbonic acid gas by the southern and upward invasion of the cold waters, and to decrease the supply of CO_2 to the atmosphere by the destruction of the lime-secreting animals. Therefore we conclude that *the ocean very greatly intensifies the secular variation of the earth's temperature, although acting as a moderating agent in the minor cycles.*

It is interesting to note what a different state of affairs we would have if the CO_2 in the ocean were simply dissolved as a gas from the atmosphere according to the laws of gas absorption. A diminution of the partial pressure of the CO_2 in the atmosphere, as postulated, would bring out of the ocean 38 to 45 per cent. of its great store of CO_2. A lowering of 5° in

temperature from 5° to 0° would only produce an increase in the solubility of the gas of 24 per cent., and from 20° to 15° of 14 per cent., and so, under such conditions, an excess of 14 to 31 per cent. of all the CO_2 in the ocean would have to be removed and consumed before a cold period could be inaugurated.

Although future investigations may cause a modification of Dr. Arrhenius' estimate, and such a change will affect some of these conclusions, the principles on which they are based will not be affected. If it be found that on account of certain intensifying agencies, or for other reasons, it is not necessary to postulate so large a decrease of the CO_2 of the atmosphere, or if this decrease is accompanied with a greater fall of temperature than 5°, then the depleting effect of the ocean will become more marked. If, however, the estimated decrease of the atmospheric CO_2 is too small, the intensive effects may be lessened, but probably not completely destroyed.

CYRUS F. TOLMAN, JR.

Editorial

It is gratifying to know that the excellent work of the Missouri Geological Survey is to be continued and that it is even proposed "to eliminate all ornamental or irrelevant fancies and go directly after the fundamental facts which make the only logical foundation for a geological survey." It is true that among the "ornamental" facts to be eliminated are such things as "Engineering Instruments, Photographic Apparatus, Laboratory Equipments" and a few others which ordinary geologists have come to consider indispensable. However, it is no ordinary man or ordinary plan of work that Missouri now has on its hands. In a recent St. Louis interview the state geologist announces that "The rocks have never been differentiated in Missouri and Arkansas"—thus setting aside at one stroke of the pen all the results of former work in the region. Fortunately such a dire condition is not to be allowed to continue, and the new state geologist proposes to issue at once a preliminary report in which "I will differentiate the rocks to a finish." He also proposes to give "photographic views of two or three of the best exposures of each rock in the state," from which we may infer that since his *Biennial Report* was issued he has fallen into evil ways and has begun to lean a little on the "ornamental" and "irrelevant" aids of other members of his profession. This new work is to be very thorough and the sedimentary rocks are to be taken, "one at a time, from Z to A."

Incidentally he will courteously give in the report a synopsis of a new "cosmic philosophy" which he has worked out "with only physics, logic and consciousness as guides." With such noble companionship it is no wonder that ordinary grammar is considered out of place. At least we may judge this to be true from such statements as, "Several dykes of diabase were crossed

in the county, as well as rumors of rich deposits, etc."[1] This sentence gives one some new light on classification and will perhaps obtain for the doubter pardon for his skepticism whether the new differentiation is to be so very thorough after all. When diabase dikes and rumors are classed together, there seems room for doubt as to the closeness of the classification. However, all things are possible to one who can explain dolomite as formed in Sargasso seas and can settle the glacial problem in one short page. The proposed preliminary report will be eagerly awaited; the *Biennial* is all too brief a pleasure.

H. F. B.

[1] Biennial Report of State Geologist, 1898, p. 36.

Reviews.

The great Ice-dams of Lakes Maumee, Whittlesey and Warren. By Frank Bursley Taylor, Fort Wayne, Ind. American Geologist, July 1899, Vol. XXIV, pp. 6–38, Pl. II and III.

Two years ago Mr. Taylor contributed to Pleistocene geology a new working hypothesis.[1] Pointing out that the recessional moraines left by certain lobes of the Laurentide ice sheet on plains or in broad smooth valleys were characterized by regularity of interval, he postulated that this regularity was caused by a definitive rhythm in the general conditions controlling the magnitude of the ice-field; whatever may have been the cause of the general wasting of the ice, its action was modified by a concurrent cause of a rhythmic nature, which alternately promoted and opposed the wasting. Under the joint action of the two causes the ice front first retreated with comparative rapidity, then halted, readvanced slowly over part of the abandoned territory, and finally halted a second time before beginning a second cycle; and each recessional moraine marks the position of the ice front at the close of such a cycle. This hypothesis, if well founded, is of far reaching importance. It affords a basis for the correlation of moraines in widely separated districts, and for the mapping of the ice sheet at various stages of its final waning. It affords a regularly graduated chronologic scheme of classification. It leads to an estimate of the duration of a definite portion of geologic time, far superior to any based on phenomena of erosion. And it probably assists in the discussion of the cause of the ice age.

When the hypothesis was first presented it was applied to the making of a time estimate. In the present paper it is applied to local geology, the correlation of moraines and associated phenomena in a district about Lakes Erie and Huron. After a general discussion of the function of the ice front as a dam to retain glacial lakes, and of the theoretic relations of successive positions of the dam to cols, and the

[1] Moraines of Recession and their Significance in Glacial Theory. Jour. Geol. Vol. V, 1897, pp. 421–465.

resulting location of shore lines and channels of outlet, an account is given of the actual positions of the ice-dam within the district and of the resulting series of glacial lakes. A map of moraines includes not only data from various sources previously publisht, but important new material, especially for the Canadian peninsula, and is adjusted to the subject in hand by the indication of the theoretic continuations and connections of partly surveyed moraines. Other maps show the glacial lakes, outlined with detail and confidence not only on the land side, where their shores are still preserved as dry beaches and terraces, but also the ice side, where all actual vestige has necessarily disappeared.

Lake Maumee, in the western part of the Erie basin, lasted during three oscillations of the ice front, growing larger with each shifting of the dam. At first its discharge was at Fort Wayne and thence down the Wabash River; afterwards part of its surplus escaped across the "thumb" of Michigan at Imlay, running westward to the Lake Michigan basin. In the later part of its life the broad upland of the peninsula of Canada was a nunatak. Lake Whittlesey, succeeding Lake Maumee in the same basin, held place for a single morainic cycle. The Canadian upland, no longer a nunatak, formed part of its northeastern shore, separating two ice lobes. Its discharge crost the thumb of Michigan at Ubly to a lower glacial lake, Saginaw, and thence ran westward through the Pewamo channel across the lower peninsula of Michigan. Lake Warren, uniting Lakes Whittlesey and Saginaw, at the level of the latter, endured for four morainic cycles, being greatly modified in outline by the successive changes of the retaining dam and becoming eventually much larger than its predecessors.

It is to be noted that the author did not delay the publication of his generalization until the ground had been wholly covered by observation nor until all the observations made use of had been verified. While guarding against misapprehension by constantly drawing the line between fact and theory, he has freely used his working hypothesis for purposes of local interpolation. To whatever extent his local generalizations are deductions from theory they will eventually, through the extension of observation be made to serve as tests of the theory.

Taylor dwells on the peculiar significance of the Ubly channel as an evidence of the existence of glacial lakes and a glacial dam, and closes with a general argument (drawn out by criticisms of J. W. Spencer) in support of the fundamental theory that the ice sheet served as a dam for the retention of lakes.

A corollary of some interest, not mentioned by the author, relates the history recorded by recessional moraines to that associated with Niagara gorge. From the beginning of the last ice retreat at Cincinnati Taylor counts seventeen moraines to Rochester, beyond which point new conditions enter, making the continuance of the analysis a matter of great difficulty. But just at the close of the term represented by these moraines the Niagara began its work, so that the moraine history is complemented by the river history. Together they represent all the time since the latest ice maximum, a period whose measurement in years is far more valuable to science than the determination of the age of the great cataract. Postulating the astronomic cycle of the precession of the equinoxes as the cause of the morainic cycle, the approximate time covered by the morainic history is computed (by the reviewer) at 315,000 years. This is so long a period in comparison with the most ample of modern estimates for the age of the Niagara that the uncertainty as to Niagara's age is of little moment in considering the sum of the two periods. Broadly stated, the hypothesis that the recessional moraines are functions of the precessional cycle estimates the time since the last maximum of glaciation at 300,000 to 400,000 years.

G. K. G.

The Influence of the Carbonic Acid in the Air upon the Temperature of the Ground. By PROFESSOR SVANTE ARRHENIUS. *Philosophical Magazine and Journal of Science*, Vol. XLI (Fifth Series) 1896, pp. 237–276. *La Revue Générale des Sciences*, Mai, 1899, pp. 1–22.

Professor Arrhenius was led to investigate this subject by the debates among the Swedish geologists upon the cause of the glacial and interglacial climates of the Pleistocene. The conclusion that none of the current hypotheses are satisfactory or at all competent to explain the observed phenomena led him to calculate the quantitative effect of any given variation in the amount of atmospheric carbon dioxide upon the temperature of the earth's surface. The fact that the carbon dioxide and water vapor are the chief agents in retaining the heat radiated from the earth's surface had long been known qualitatively and even the relative values of the selective absorption of radiant energy for the various atmospheric gases had been determined, but it remained for

Professor Arrhenius to show the exact effect of any given change in the carbon dioxide content of the atmosphere upon the surface temperature of the earth.

The essential work of the physicist and mathematician having now been done by him, it remains for the geologist to investigate the various sources of supply and depletion of carbon dioxide and to determine if possible if there have been any variations of such an order of magnitude as to produce the results observed.

Professor Arrhenius explains in his papers that the air retains heat (light and dark) in two different ways: (1) The heat suffers a selective diffusion as it passes through the air. This is greatest for the rays having short wave-lengths (ultra-violet) and insensible for those of long wave-lengths which form the chief part of the radiation of a body of the temperature of the earth, viz., 15° C. (2) The gases themselves have the power of absorbing selectively the light and heat of certain wave-lengths. The carbon dioxide and the water vapor have this power of selective absorption to a far greater extent than the oxygen, nitrogen or argon, and this absorption is not distributed evenly throughout the spectrum but occurs in certain definite bands which are best developed in the ultra-red portion which represents the rays with long wave-lengths such as are given off by bodies with a low temperature.

There are two ways in which to measure the amount of the heat absorption by the carbon dioxide and the water vapor: (1) by measuring directly the amount of heat absorbed by such quantities of these gases as they appear in the atmosphere, and at a temperature of 15° C., and (2) by measuring the amounts of heat received from the full moon at different heights above the horizon. The amount of carbon dioxide through which the rays pass is evidently a function of altitude of the moon above the horizon, while that of the water vapor depends both upon the altitude and the humidity of the air.

Professor Arrhenius takes the second method and from Professor Langley's observations on the heat received from the full moon at various altitudes above the horizon he calculates the amount of heat absorbed by the two gases by an atmosphere having the present average amount of carbon dioxide and the average amount of water vapor, viz., ten grains per cubic meter at the earth's surface. The full moon has, however, a surface temperature of 100°, and he introduces the corrections necessary to apply the above to a body with the temperature of 15° C.

With these data it is not difficult to calculate the effect of any change in the amount of carbon dioxide upon the temperature of the surface of the earth. The temperature of the earth's surface is theoretically in equilibrium with that of the atmosphere. Now if by any increase in the amount of the carbon dioxide the atmosphere retains more heat than before, it will radiate more heat to the surface of the earth. The surface temperature then will rise until there is again an equilibrium between the two. This rise is governed by Stefan's law which states that the intensity of the radiation is proportionate to the fourth power of the e r

From these data Professor Arrhenius finds that if the carbon dioxide is increased 2.5 to 3 times its present value, the temperature in the arctic regions must rise 8° to 9° C. and produce a climate as mild as that of the Eocene period. A diminution to 0.62 to 0.55 of its present value must cause a fall of from 4° to 5° C. and give us a glacial period.

It is to be noted that in every case throughout the calculation Professor Arrhenius has preferred to slightly underestimate the effect of the carbon dioxide than to risk a possible overestimate. Also where he has been compelled to use interpolation the limit of error has been well within the degree of accuracy of the observations upon which they are founded.

The tremendous interest of these considerations, not only as a basis for the interpretation of the past history of the globe but also for the prophecy of its future, demands an investigation of the problem along the lines of direct experiment, as a supplement to the elegant calculations of Professor Arrhenius. CYRUS F. TOLMAN, JR.

Special Report on Gypsum and Gypsum Cement Plasters. By G. P. GRIMSLEY and E. H. S. BAILEY. University Geological Survey of Kansas, Vol. V. Pp. 183, 30 plates. Topeka, 1899.

Among the minor mineral industries of the country those connected with gypsum have been, so far as literature is concerned, heretofore neglected. The present report is accordingly particularly welcome. The papers so far accessible have been, in the main, devoted to the description of local deposits and the technology of the gypsum industries has not been described before in any adequate manner. The present volume includes not only a description of the Kansas gypsum beds

but brief notes on the gypsum of other states and countries and a full discussion of the mining and milling processes. The body of the work is by Dr. Grimsley while Professor Bailey contributes a welcome chapter dealing with the chemistry of the subject.

In 1897 Kansas produced 50,045 tons of gypsum which had a value of $252,811. It was a little behind Iowa in production and ahead in values; the difference being in the large proportion of the Iowa product sold as land plaster. Aside from these two states Michigan and New York are the main producers. The Kansas gypsum is found in three fields; the Northern or Blue Rapids area mainly in Washington and Marshall counties, the central or Gypsum City area of Salina, Dickinson, and Marion counties, and the southern or Medicine Lodge area in Comanche and Barber (misprinted Barton on map) counties. The beds occur in the Permian of Prosser's classification and the deposits include the original rock deposits and the derived gypsum earths which are of recent origin. These gypsum earths are the distinctive beds of the Kansas-Oklahoma district and are thought to be marsh deposits deriving their peculiarities from the secondary deposition of gypsum in clays. They are used in the production of gypsum cements and are mined by ordinary surface methods. The rock gypsum is won by underground mining on a room and pillar system, of which a more detailed account would have been valuable, and are used in the production of plaster of Paris and other products.

The Kansas milling practice does not seem to differ from that of other districts especially, though the Stedman disintegrator has been introduced and a cooling air blast is used at one point to elevate the calcined plaster. Here as elsewhere grinding is in the main done by stones and it seems peculiar, in view of the great progress of recent years in fine grinding machinery, that the numerous experiments in the direction of cheaper and more expeditious grinding have never borne fruit in the gypsum industries. Burning is done in the ordinary Marsh calcining kettle. It would seem that in the case of the gypsum earths at least the rotary furnaces now so much used could be applied to advantage.

In the discussion of the set of the plaster Dr. Grimsley has contributed some highly interesting and valuable microscopic studies in which he shows, in brief, that the strength of the set plaster depends upon the formation of a network or felt of fine lath-shaped crystals and that the quickening agents in this setting process are the few small

crystals present in the dry plaster. This accords well with all the known facts in the case and is furthermore in line with Jameson's observations on the setting of Portland cements. It explains some of the peculiarities of the behavior of retarders though in the matter of that vexed subject but little that is new is brought out. If the subject of the strength, and rapidity of set of the gypsum cements could have been gone into a little and illustrated by tensile strength and other tests it would have added greatly to the value of the book and have aided in defining the sort of situations in which these cements could be used to best advantage. In the form of hard white finish they now dominate the market so far as interior work is concerned but the advisability of using them for wall work in any general way is open as yet to some question. This is particularly true in view of the strength and cheapness of magnesian limes and the availability of non-sulphate cements.

Dr. Grimsley's report is a valuable one, particularly in its technical as distinguished from its geological phases. It will undoubtedly have a large influence on the gypsum industry of the state and is a credit to the vigorous Kansas Survey. H. F. Bain.

American Cements. By Uriah Cummings. Pp. 299, 8 vo. Rogers & Manson, Boston. 1898.

In the rapid introduction of Portland cements in this country the importance and value of the Roman cements bid fair to be overlooked. At present there is what the author fittingly nominates a "craze" for quick setting, high testing cements, and the slower setting, cheaper grades are looked upon in many quarters as of very little value. Mr. Cummings' long experience in the manufacture of cement and his wide interest in the subject admirably fit him to discuss it. In this little book he has gathered together much scattered information and has added very much from his own experience. His interpretations of the chemical processes involved in the making and the setting of cements will, doubtless arouse much opposition; particularly in his plea for the magnesian cements, but where so much is uncertain any hypothesis backed with such facts as Mr. Cummings marshals must necessarily receive careful attention. Taken as a whole the book is one of which no one interested in cements and the utilization of our limestones and shales, can afford to remain in ignorance.

H. F. Bain.

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THE

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THE PLIOCENE SKULL OF CALIFORNIA AND THE FLINT IMPLEMENTS OF TABLE MOUNTAIN

The celebrated skull from Calaveras county, California, claimed to have been found at a depth of 130 feet in the auriferous gravel deposits of a Pliocene river "beneath the lava, in the cement, and in close proximity to a completely petrified oak" was exhibited by Professor J. D. Whitney at the Chicago meeting of the American Association for the Advancement of Science in the month of August 1868.

At that time the attention of the Association in general session was directed by the writer to certain conditions and peculiarities of the relic which made it unreasonable to accept it as coming from the deep gravels of a river. The objections then made to the skull as evidence of man's great antiquity do not appear to have been reported or recorded, having been given in the course of the discussion and not in a paper of record.

One chief reason for the rejection of the skull as coming from the gravelly bed of an ancient river is the entire absence on its surface, or on its broken edges, of any marks of attrition. If the skull had ever been rolled along the bed of a river with the bowlders and gravel, it would bear the marks of the violent pounding and wearing action to which any bone or object occurring in such gravels is subjected. In fact, a hollow bone or least

of all a human skull, could not remain intact, or even so well preserved a fragment as the skull in question, under such violent and abrasive conditions — conditions resulting in the rounding of the edges of pebbles and bowlders and in flattening out pellets of gold.

Those familiar with the auriferous gravel deposits, even of slight depth in modern rivers, know how the smaller materials fill every interstice of the bedrock, and, in the case of the bones of the mammoth and of the mastodon, how the foramens of the teeth and any cavity of the more solid bones of the jaw become filled up solidly with fine gravel, often cemented, and sometimes holding pellets of gold. Bones found in river gravels show the effects of attrition and wearing. All the thin plates, asperities, and sharp edges disappear under the violence to which they are subjected in running water transporting gravel.

In the Calaveras skull no such conditions are found. It was found hollow, nearly empty as left by the decomposed brain, not filled with gravel or sand, of a river deposit, and the broken edges were sharp and not abraded. This condition alone is sufficient evidence that the skull and the gravel in which it was said to occur were not parts of the same deposit and contemporaneous in origin in the river bed.

But certain objects were found in the skull — other bones, an ornament of some kind, and the shell of a snail, partially cemented together and to the skull by a deposit of calcareous tufa. All these objects indicate surface origin and interment, and their presence is not reconcilable with any theory of the entombment of the skull in auriferous, deep-seated gravel.

Since the exhibition of the skull at Chicago a full description of it, illustrated by a full-sized drawing, has been published by Professor Whitney.[1] By reference to this drawing it will be seen that all the fractured edges of the bones (for it is not an entire skull) are sharp and angular, and do not show signs of abrasion.

[1] Contributions to American Geology, Vol. I. The Auriferous Gravels of the Sierra Nevada, California, by J. D. Whitney, 4to, Cambridge [U. S.], 1880.

The presence of calcareous tufa is adverse to the theory of the occurrence of the bone in the deep gravel. The tufa is an incrustation; its presence indicates surface evaporation and concentration of calcareous waters. It does not occur in this case as a permeating solution forming a cement for deep gravel, but as an investing crust deposited on and around the bone, although it is claimed that a chemical change in the bone has resulted. The cementing material of the deep gravels is generally siliceous rather than calcareous, or if calcareous it permeates the mass and unites the pebbles and grains of sand into a rock-like mass.

The description states: "In cutting away the mixed tufa and gravel which covered the face and base, several fragments of human bones were removed, namely, one whole and one broken metatarsal; the lower end of a left fibula and fragment of an ulna as well as a piece of a sternum." "These bones and fragments of bones might have belonged to the same individual to whom the skull had appertained, but besides these there was a portion of a human tibia of too small size to be referred to the same person." There were also fragments of the bones of a small mammal. Under the molar bone of the left side, a small snail shell was lodged, partially concealed by one of the small human bones which was wedged into the cavity. This shell was recognized by Dr. J. G. Cooper as *Helix mormonum*, a species now existing in the Sierra Nevada. Cemented to the fore part of the roof of the mouth was found a circular piece of shell four tenths of an inch in diameter, with a hole drilled through the center which had probably served as an ornament. Several very small pieces of charcoal were also found in the matter adhering to the base of the skull."[1]

I have given this full quotation that there may not be any mistake. Professor Whitney is certainly to be commended for his complete presentation of evidence which is sufficient, in my judgment, to show that he was dealing with the relics of an Indian burial place rather than a fossil from the ancient gravels. It is not possible to conceive that this mixture of human bones

[1] *Ibid.*, p. 268.

of portions of at least two individuals, an ornament, charcoal, and a snail of an existing species, or of any species — a thin fragile shell — could travel together in the bed of a river and be concentrated in one spot, in fact, in one mass. It is incredible.

Much stress in the discussion upon the authenticity of this relic is placed upon the statement of the miner that he found the skull in his mine; that he found it there lying on the side of the channel with a mass of driftwood. While this statement of finding bones and driftwood together at that depth tends to discredit the statement it may be accepted, but with the question, how did the skull get there? The best explanation is found in the statement of another miner who had a claim in the vicinity that in going home one evening he picked up the mass, and, in passing his neighbor's shaft, threw it down to frighten him, and get him to go home to supper. The skull was then "discovered" and taken to Angel's Camp, where, after resting for a time in the window of the apothecary, it attracted the attention of Dr. Jones, of Murphy's camp, and was made known to the scientific world.

This is the story as told to me by eyewitnesses and participants. Thus the silent but convincing testimony of the skull itself, and of human testimony, are against its reception as evidence of man's antiquity.

But while the authenticity of this skull as a Pliocene fossil is questioned and challenged by most authorities, it is often accorded a quasi-recognition rather than an unqualified rejection. For example Professor G. Frederick Wright relying partly upon new evidence presented by Mr. Becker at the meeting of the Geological Society of America in 1891 appears to be convinced of the genuineness of the skull and states "it would seem unreasonable any longer to refuse to credit the testimony."[1]

The most satisfactory and common-sense discussion of the merit of this skull as evidence with which I am acquainted is that by Principal Dawson in his work enitled *Fossil Men.*[2] After

[1] WRIGHT, Man and the Glacial Period, p. 296.

[2] Fossil Men and their Modern Representatives, by J. W. DAWSON, LL.D., F.R.S., F.G.S., Montreal, 1880, pp. 344–347.

giving five cogent reasons for the non-acceptance of the Calaveras skull as evidence of the existence of man in Pliocene times he sums up as follows: "The above reasons are, I think, quite sufficient to warrant any geologist in declining to accept the human remains of the California gravels as other than those of American Indians of modern periods."

Quatrefages makes two references to the Calaveras skull. In one he writes: "Much has been said about the skull discovered by Whitney in California. Unfortunately, the description of this specimen has not appeared so that doubts have on several occasions been expressed as to the existence of the fossil itself. The recent testimony of M. Pinart has removed them, but has at the same time created the most serious doubts as to the antiquity of this specimen, which seems to have been found in disturbed grounds."[1]

Again, in discussing the succession of the two great types of skulls, he states "that at present everything argues in favor of the anteriority of the dolichocephali. In America the only known fossil skull leads to the same conclusion."[2]

In the foregoing citation of the conclusions of Dr. Dawson it will be noted that he groups together the evidence presented by the skull and those from other human remains in the California gravels. This tendency is shown, also, by Dana, who, after mentioning the doubts of the authenticity of the skull, writes: "Whitney also mentions the discovery of flint implements in the auriferous gravel in other parts of California. The fossil plants of the gravels are referred to the Pliocene (or partly Miocene) by Lesquereux. The few mammalian remains include the Champlain mastodon and elephant, but in some places Pliocene species. Some recent land shells were contained in the earth filling the cranium."

To anyone not familiar with the localities, the modern and ancient gravels, and the occurrence of flint implements, the

[1] A. DE QUATREFAGES, The Human Species. Int. Sci. Series, D. Appleton & Co., 1888, p. 291.

[2] Ibid., p. 299.

conclusion would, I think, be a fair one that both the mammalian remains and flint implements occur in the same gravels, or horizon, in which the skull is claimed to have been found. So far as my knowledge extends this is not so. I am not aware that it has been claimed that flint implements, or even the remains of the mammoth and the mastodon have been found where the skull was said to occur. That flint implements have been found in association with the remains of the large mammals there is little doubt, but as to the age of such gravels, and whether or not the implements may not have been washed in from higher levels or superficial deposits of a far later origin I am not able to bear conclusive testimony. The subject requires most careful and extended investigation, the fact being always kept in mind that in the gigantic placer mining operations of California there is a concentration upon the bedrock of all heavy objects which may have been originally in the surface soil or any part of the banks of gravel between the soil and the bed of the ancient river.

In all river and creek channels of modern streams, and even in what are called dry arroyos or gulches, there is a possibility that in seasons of flood or of great accumulation of rushing water from showers or cloud-bursts objects lying on the surface, such as stone implements, pestles, mortars, metates, flint chips, etc., may be swept onwards in the gravel and sunk to the very bedrock and become buried by deposits twenty feet thick, and possibly more and all in the space of an hour or less. The loss of iron safes in different places in California and Arizona, the safes wholly disappearing, and similarly the loss of quicksilver in flasks while crossing a swollen torrent are familiar examples. Heavy objects, like gold, in swiftly moving water are carried to the lowest point possible and are covered from view by heavy deposits of gravel and bowlders. The finding, therefore, of Indian stone mortars at a considerable depth in gravel in a modern stream valley is not good evidence of antiquity.

In regard to the concentration of objects on the bedrock of placers, when there is sluicing or washing by the hydraulic method on a large scale, miners are familiar with the fact that

nails, spikes, shot and bullets are frequently found in cleaning up the sluices. In one instance, known to the writer, a small cast-iron casket containing the remains of an infant in alcohol was found in cleaning up a sluice after a long run by the hydraulic process upon a bank of gravel some thirty feet deep.

THE TABLE MOUNTAIN RELICS

Much has been written regarding the flint implements in great variety and perfection of workmanship collected from Table Mountain near Angels Camp by the late Dr. Snell. It was stated by him that they were found under Table Mountain, the lava cap of an old Pliocene river. I must confess to have for a time lent credence to this view of their occurrence. I reported the facts as I then understood them at the Congress of Archæologists at Paris in 1867.

But later investigations have satisfied me that these relics were entombed in the surface soil and accumulations of the slope of the mountain just below the jutting, overhanging cliffs of the lava, which afforded excellent protection from the weather, and were no doubt occupied as habitations or dwellings analogous to the cliff-dwellings of New Mexico and Arizona, but without any, now visible, exterior wall or construction. There is no reason for associating these flint implements in any way with the occurrence of the skull, or with the bones of the great mammals.

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University of Arizona,
March 1899.

A GRANITE-GNEISS IN CENTRAL CONNECTICUT

THE granite-gneiss[1] to be described occurs on both sides of the Connecticut River, some five miles east of Middletown. It cuts the schists of the eastern crystalline area of Connecticut, a short distance east of their contact with the Triassic sandstone. Its distribution is shown on the accompanying map (Fig. 1).[2] It forms an oval area in the mica schist, and, at its northern end, is continued northward by a series of beds varying from a few inches to many feet in thickness, lying parallel to the enclosing schists. The largest of these is a direct continuation of the main granite-gneiss mass, and all are probably parts of the same intrusion. As the distance from the main area increases, these beds gradually thin out and disappear from the schists.

The only previous work on the geology of this region is that of Percival,[3] who recognized this granitic rock only on the east side of the river, and united that part of it with a large mass of granitic-gneiss to the north, with which it is probably not connected. He does not consider the origin of any of the gneisses. It has not been possible to use Percival's results except in a general way, and the work done in this region by the writer is essentially *de novo*.

The rock is a medium to fine-grained biotite-gneiss. The color varies from white or light gray to dark gray, according to the amount of biotite. In a few cases the rock is almost or quite massive, but usually it is well foliated. The granite-gneiss is cut by several sets of joint planes, of which one set is nearly

[1] In this paper a gneiss of granitic composition and of unknown origin is called a granitic gneiss; if of igneous origin, a granitic gneiss. See C. H. GORDON in Bull. Geol. Soc. America, Vol. VII, p. 122.

[2] That portion of the western boundary of the granite-gneiss north of the river is largely covered by river terrace, and for about a mile along the eastern border, near Great Hill pond, outcrops are rare. With these two possible exceptions, the "supposed boundary," so-called, is believed to be very nearly the true boundary.

[3] J. G. PERCIVAL: Report on the Geology of Connecticut. 1842, pp. 222, 224.

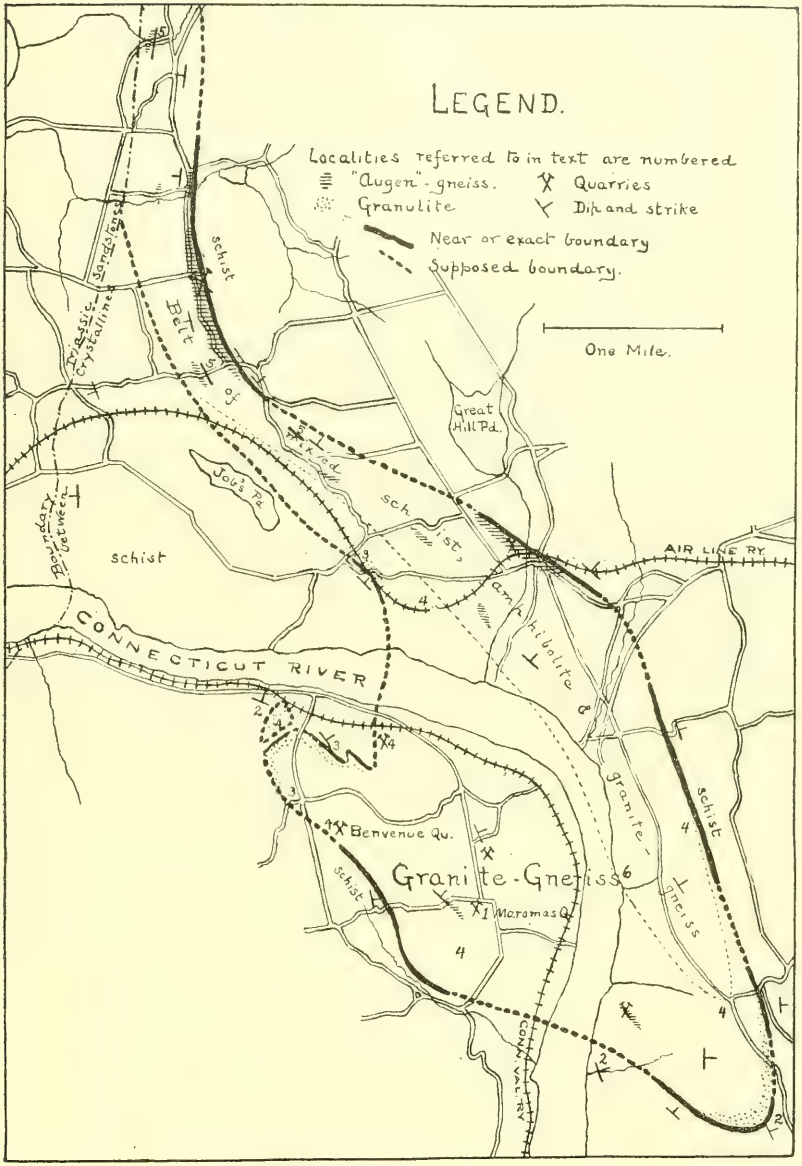


FIG. 1. Map of the Granite-Gneiss Area.

or quite parallel to the foliation, giving the rock a bedded appearance (Fig. 2. Map, 1). Several quarries have been opened, and the attempt has been made to market the rock as a building stone. It is handsome when first quarried, but stains quickly, and so is of use only for foundations, etc.

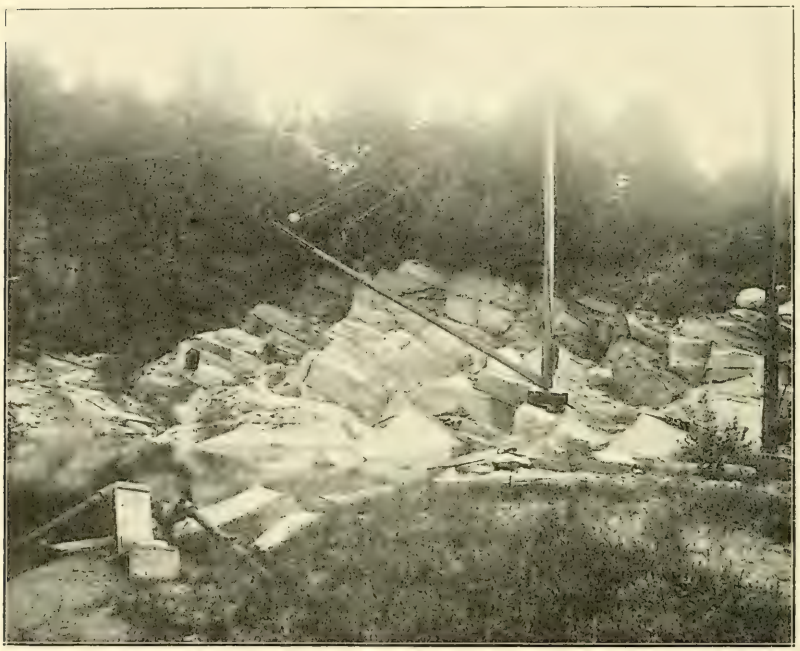


FIG. 2. Bedded Granite-Gneiss, Maromas Quarry.

I. THE GRANITE-GNEISS IS ERUPTIVE.

1. *General stratigraphical features.*—A rounded or elliptical form, like that taken by this granite-gneiss, is common in the case of eruptive granites. The narrow belt that runs into the schists from its northern end is decidedly subordinate to the larger mass of which it is an offshoot. The northwest direction of the longer axis of the granite-gneiss area is doubtless determined by the strike of the enclosing schists. The irregularity of the boundary on the west side of the granite-gneiss indicates

the same origin as does the general form of the area. At several points, too, along the western border and southern end of the granite-gneiss (Map, 2), the line of contact cuts across the strike of the foliation of the enclosing schists. This is not noticeable at all of the localities at which actual contacts between the two rocks can be seen, though it is at one or two, but it comes out on mapping the dip and strike of the schist. This foliation of the schists seems to be a stratification foliation and not a secondary structure, because (1) it is parallel to the alternating beds of schist and fine-grained micaceous gneiss which make up the schist formation, and (2) the dip and strike of the foliation is not uniform throughout the area, but varies through all possible changes.

2. *Contact Phenomena.* — At some of the localities where the exact contact of the two rocks is seen there is the clearest proof within narrower compass of the eruptive character of the granite-gneiss (Map, 3). The line of contact is frequently irregular, the granite-gneiss often cuts across the foliation of the schist or sends tongues into the schist; and sheets of schist, partly torn from the main schist mass, occur projecting into the granite-gneiss.

As the granite-gneiss occurs in the midst of completely crystalline schists, any considerable contact metamorphism of the surrounding rocks would not be expected. In many granite intrusions into crystalline rocks no contact metamorphism is seen. In the present case besides quartz, feldspar, biotite and occasionally hornblende, the schists carry at times garnet, staurolite, cyanite and tourmaline. The latter often seems to be connected with the pegmatite dikes which cut the schist. None of these less common minerals is more abundant near the contact or can be considered a result of the metamorphic action of the granite-gneiss.

It is sufficient merely to mention at this point another evidence of the igneous character of the granite-gneiss, namely, the fine-grained granulitic character which it assumes at some points about its border. This endomorphic metamorphism of the granite-gneiss will be described more fully below.

3. *Inclusions.*— One of the most striking proofs of the eruptive character of the granite-gneiss is the presence of inclusions of schist within its boundary. These are seen at a number of localities in widely different parts of the area, and commonly not far from the border (Map, 4). They vary in size from a few inches to many feet in length, and may be of linear or very irregular form. The material composing them is a biotite-schist, or a fine-grained biotite-gneiss, similar to the schist series around the gneiss and often showing the minute folding which in places is characteristic of the latter. The inclusions occur both in the more massive and in the more foliated varieties of the granite-gneiss, and also in the granulitic facies which occurs at some points about the border.

At this point it is well to describe an occurrence which, while not a proof of the igneous origin of the granite-gneiss, is best understood in connection with inclusions. At several localities in the southern half of the granite area, occur isolated bands of schist of uniform thickness, running parallel to the foliation of the immediately adjacent granite-gneiss. They cease at a greater or less distance, but their actual termination cannot be seen because of lack of outcrops. They show sharp contacts with the enclosing granite-gneiss and in one or two cases tongues of the latter enter them at a low angle, showing them to be inclusions. And as even those schist bands which do not show an apparent eruptive contact lie within an area of rock which is certainly in largest part eruptive, it is most likely that all such occurrences are inclusions. These band-like inclusions vary from a few feet to several score of feet in thickness, and are sometimes several hundred feet in length. Their direction is variable and is independent of the foliation of the schist lying nearest to them outside of the granite-gneiss area. Their sheet-like character was evidently determined by the strong foliation of the schists through which the granite-gneiss is here eruptive. It is, however, along the east side of the granite-gneiss that the amount of this foreign material is greatest. Here the mica-schist is associated with considerable dark,

thin-bedded gneiss and schist which contain both biotite and hornblende, and with amphibolite. These dark bands of gneiss and schist are not here variable in direction, but run parallel to the boundary of the granite-gneiss, and agree in dip and strike with the schist east of it and with themselves. Yet undoubted igneous contacts occur between these dark gneisses and schists, and the lighter granite-gneiss which occurs between them. The granite-gneiss which in other parts of the area replaced almost entirely the schist through which it came, here merely forced its way into fissures parallel to the foliation of the country rock. The distribution of this belt of mixed rock is shown on the map. As already pointed out the granite-gneiss gradually disappears as we go north.

4. *Schlieren.*—In a number of places where the granite-gneiss is most massive, it encloses patches of darker material or schlieren—basic segregations of the granite magma. These are best seen in the Benvenue and Maromas quarries. The schlieren are of uniform composition, finer grained than the enclosing rock, have a larger proportion of biotite, and often contain hornblende, which is almost wholly wanting in the ordinary granite-gneiss. They are rounded, elliptical or irregular in outline and always elongated parallel to the foliation so as to form lenticular patches and in extreme cases bands. This lenticular and frequently sheet-like form is probably due to movement in the partly differentiated magma previous to thes olidification of the rock. Such darker and more basic portions are very common in granites and have been regarded as a strong indication of the eruptive origin of the rock in which they are found.[1] In the Benvenue quarry where these schlieren occur, the rock also holds irregular inclusions of schist.

Associated Pegmatite Dikes.—Although the presence of abundant pegmatite dikes about a granitic area would not in itself be a proof that the rock in question was eruptive, it would be an interesting and corroborative fact. In the opinion of

[1] ROSENBUSCH: Massige Gesteine, p. 62; G. H. WILLIAMS, XV., Ann. Rept. U. S. Geol. Surv., p. 662.

Brögger,[1] Williams,[2] Crosby,[3] and others, the presence of one or more parent masses of less acid plutonic rocks is to be expected in such regions of abundant pegmatite dikes. The pegmatite dikes of central Connecticut are abundant, and are widely known for the variety and beauty of the minerals they have furnished collectors. They occur in dike-like masses in both gneisses and schists, but more abundantly in the latter, and they both cross and run parallel to the foliation of the enclosing rocks. Their contact with the gneisses and schists is sharp and they frequently contain inclusions of the same. There are two other considerable areas of granitic biotite-gneiss in the region, one to the south and the other to the north of the area under consideration. The former shows no sign of igneous origin and seems to be the basal member of a series of conformable gneisses and schists which form a northward pitching anticline. The study of the latter area is not yet completed. The evidence so far collected seems to indicate that it is largely composed of eruptive material; but even so the Middletown granite-gneiss is more centrally located with reference to the dikes and would more likely be the rock genetically connected with them. The schists which surround it are more filled with pegmatite. The hills near the Connecticut River, just west of the granite-gneiss, are known as the "White Rocks," from the prominent outcrops of pegmatite, and the schist east of the granite-gneiss is also cut by quantities of the same rock. This abundance of pegmatite dikes would lead us to expect one or more centrally located masses of granite with which they could be connected, and the area of granite-gneiss we have been describing seems to answer the expectation It does not appear that the dikes radiate from it; rather they follow in a general way the foliation of the schist. They do, however, appear to grow more abundant toward the granite-gneiss.

In connection with the evidence brought forward to show the eruptive nature of the granite-gneiss it is interesting to know

[1] Zeit. für Kryst., Vol. XIV, 1890, or Canadian Rec. Sci., Vol, VI, p. 33.

[2] Fifteenth Ann. Rept. U. S. Geol. Surv., p. 680.

[3] CROSBY and FULLER, American Geologist, Vol. XIX, p. 151.

that the granitic biotite-gneiss to the south, which has already been mentioned as constituting the lowest member of an anticlinal fold, and which appears from its field relations to be a sedimentary rock, wholly lacks the various characteristics of igneous origin possessed by the granite-gneiss. The mineralogical and structural characters which come out in a microscopical study of the rock, and which will be described below, are also in harmony with the belief that the granite-gneiss, in spite of its general and pronounced foliation, is an igneous rock.

II. PETROGRAPHY OF THE GRANITE-GNEISS

1. *The ordinary type.*—The ordinary form of the granite-gneiss is a light-colored, rather fine-grained biotite-gneiss. The amount of biotite varies considerably. Where it is most abundant, the rock is a dark-gray, well-foliated gneiss; where least abundant, the rock is light-gray and of a quite granitic appearance. In no case does it become perfectly massive. The grain of the rock allows of its being split along the foliation into curbstones, but not, as in the case of some of the other gneisses of the region, into flagstones. In the main body of the granite-gneiss the strike of the foliation is approximately N. 45° W.; the dip, 30° N. E. Joint planes cut the granite-gneiss in several directions, one nearly or quite parallel to the foliation, others at right angles. The rock is handsome when first quarried, but has proved useless as a building stone, because it rusts on exposure.

Microscopically the rock is a granitic mixture of feldspars and quartz, in which lie small plates of biotite. The biotite is abundant, generally with a pronounced parallel arrangement, to which the foliation of the rock is due. Hornblende is almost wholly absent. In a single section green hornblende occurs in amount subordinate to the biotite and it can be seen in a very few exposures in the field. The feldspars usually present an allotriomorphic, granitic aggregate of grains. Orthoclase is most abundant. An acid plagioclase is of common occurrence. Microcline also occurs in smaller and more irregular grains.

Both orthoclase and microcline frequently show a fine microperthitic intergrowth, with a second feldspar. In a larger number of sections some orthoclase and plagioclase grains show a granophyric intergrowth, with a second mineral, probably quartz, which takes the form of narrow irregular, curving or angular inclusions, converging toward the center of the feldspar grain. This granophyric intergrowth is absent from the probably sedimentary gneisses to the south, and seems to be characteristic of those of igneous origin. Quartz occurs in irregular but somewhat rounded interstitial grains, and is also common in drop-like inclusions in the feldspars, which occasionally approach a a dihexahedral shape. Titanite, in small, rounded, and lenticular grains, is the most common accessory. A very little apatite and magnetite occur. In about one half of the sections there is evidence of a slight amount of crushing. In the section where this is best shown, some of the quartz grains have been elongated, broken into separate areas, and granulated about their border and along lines of fracture; and between the feldspar grains are lines of smaller grains, which seem to have come from the fracturing of the feldspar. Yet in this section considerable portions show no evidence of crushing, and in many slides no proof of crushing exists.

2. *Schlieren.*— The biotite-gneiss, especially where it is more massive, often contains schlieren of darker color and finer grain, which have already been referred to and partly described in the discussion of the igneous origin of the granite-gneiss. Sections from these schlieren resemble closely the ordinary granite-gneiss. They are granitic in structure, but with a distinct foliation. Green hornblende is present, but is less abundant than the biotite. Orthoclase, plagioclase, and microcline occur in abundance in the order named. A few feldspar grains show the granophyric intergrowth already mentioned. Quartz and microperthite are absent. Titanite is a common accessory. The presence of hornblende and absence of quartz, while keeping the other essential structure and characters of the granite-gneiss, indicates that these darker patches are an integral part of the

granite-gneiss, only somewhat more basic than the general rock. The absence of any evidence of crushing in the sections shows that their present lenticular and banded form was attained while the rock was still unsolidified.

3. *The "augen"-gneiss.*— Frequently the granite-gneiss becomes a decided "augen"-gneiss. Its distribution is indicated as nearly as possible on the map. It attains its best development along the northeastern border of the granite-gneiss and in the narrow tongue that runs north into the schist. The "augen"-gneiss often passes gradually into the ordinary granite-gneiss, with which it is identical in mineralogical composition and in structure, with the single exception of the occurrence of sub-porphyritic feldspar crystals and aggregates. A surface broken at right angles to the foliation shows a light gray gneiss, dotted with more or less distinct "augen" of white or pink feldspar, averaging three fourths of an inch in length, and with a parallel arrangement, around and between which run the lines of biotite flakes. The feldspar of the "augen" often reflects light as a single crystal, either simple or a Carlsbad twin, and rarely this crystal is roughly rectangular, yet it never possesses crystal boundaries. Quite commonly the cleavage surface of these broken crystals shows dull rounded areas of feldspar which are differently oriented grains included within the larger crystal. Where a single crystal occurs it forms the irregularly margined core of the "auge" and is surrounded by a dull white rim composed of an aggregate of fine feldspar grains. As the core is pink and the rim white, there is a further contrast between the two. Much more often than not, however, the reddish core does not reflect as a unit, but consists of an aggregate of grains, still flesh-colored and coarser than the rim. In other cases the "augen" consist of aggregates of white feldspars without any reddish cores.

It looks very much in the hand specimen as if those reddish cores of the "augen," which are composed of an aggregate of grains, were derived from the fracturing of single grains, which in some cases seem to remain partly intact at the center. But

where such an aggregate is examined microscopically it is seen to be composed of feldspars of different species which show no evidence of crushing. One section (Fig. 3) showed such an aggregate consisting of a very irregular Carlsbad twin of orthoclase at its center, partly or completely enclosing irregular grains of orthoclase, plagioclase, and microcline, all containing small rounded grains of quartz. There was no evidence of crushing; no evidence of derivation of the smaller grains from

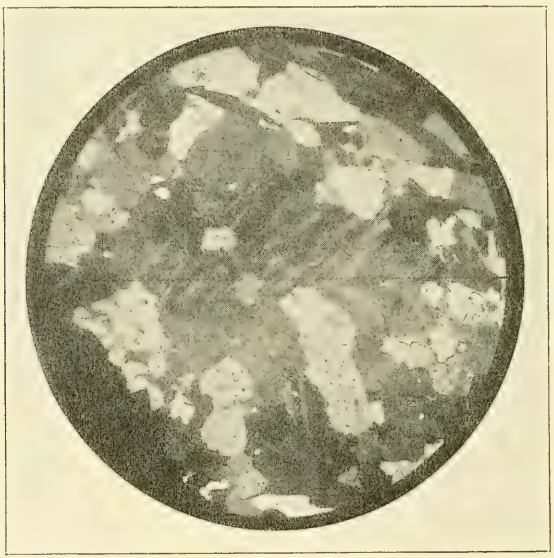


FIG. 3.— An "auge" of the "augen"-gneiss (× 18). The dark area on the upper right side is beyond the border of the section. Opposite, below, is the border of clear feldspar grains with a little biotite.

the central orthoclase grain. About this central aggregate was a zone of clearer feldspars. The red cores, then, of the "augen," both single grains and aggregates, are original crystallizations. The case may be somewhat different with the white rims which in many cases surround the red cores. These do show some evidence of crushing, and may be in part derived from peripheral crushing of the red cores, possibly accompanied by some recrystallization, for the feldspars here have a fresher appearance

than those in the central part of the "augen." Yet the absence of evidence of extensive crushing, and the fact that many of the "augen" consist wholly of white aggregates of feldspar which under the microscope show no evidence of crushing, lead us to suspect that even these white aggregates, which sometimes occur as borders around the red cores and sometimes constitute "augen" by themselves, may be, in large part, original crystallizations. The fact that these "augen" do not include to any extent plates of biotite, but that the lines of biotite flakes curve around them, seems to point to the formation of the "augen" previous to the complete solidification of the rock. The "augen"-gneiss, like the granite-gneiss of which it is a local variation, is of igneous origin. If we suppose that the first step in its formation was the separation of small orthoclase individuals or aggregates of feldspar, mainly orthoclase, but containing plagioclase and microcline, which received their parallel arrangement before the final solidification of the rock, and which may have been subsequently somewhat reduced by crushing, we shall have the most probable explanation of the "augen"-gneiss phase of this granite-gneiss.

The foliation of the granite-gneiss does not seem to be in the main a dynamic result. Evidence of crushing is found in many sections in the form of wavy extinction of the quartz and lines of finer material between the larger quartz and feldspar grains, and crushing may be responsible in part for the parallel structure of the rock. Yet in many sections of the well-foliated gneiss the microscope shows no evidence of crushing at all. It seems more likely that the arrangement in a common plane of the biotite and, in the "augen"-gneiss, of the often rather tabular grains of orthoclase is a result of movement in the partly solidified magma. The character of the schlieren points to the same conclusion. In ordinary granites the schlieren are not stretched, but are roughly equidimensional, and such we may suppose their original form to have been in the present case. Had they been drawn out to their present distorted condition subsequent to the solidification of the rock, they could hardly

fail to show evidence of such a movement in the distortion and crushing of their individual mineral particles, but such is not the case. And a rock subjected, while still incompletely solidified, to such an extensive movement as is indicated in the present instance by the form of the schlieren, would naturally have the elements which had already crystallized out, in this case biotite and, locally, individual grains and aggregates of feldspar, arranged in a more or less parallel manner.

4. *Granulite.*—For a mile along its western border, and for a somewhat greater distance about its southern end, the granite-gneiss shows a granulitic facies towards the contact. At other points both the "augen"-gneiss and the ordinary granite-gneiss may occur unchanged in immediate contact with the schist. The width of this granulite border is not constant; it varies from two or three feet to many yards. Where typically developed, it is a fine-grained, light gray or brownish rock, sometimes pure white and lacking all traces of dark minerals. This pure white granulite is present only at a few places and immediately at the contact. Small garnets are usually present. The rock has asugary texture, and when somewhat weathered often crumbles under the pressure of the fingers. Microscopically it is a fine-grained aggregate of orthoclase, an acid plagioclase, microclineand quartz. The structure is the so-called granulitic of M. Levy[1] and the panidiomorphic of Rosenbusch.[2]

The quartz and feldspar form an aggregate of variously oriented rounded grains of uniform size, which are not, however, bounded by crystal planes. With the scarcity of biotite, the foliation becomes indistinct or wanting. In one case garnet grains form fine lines on the broken edge of the rock. No evidence of crushing exists.

[1] M LÉVY: Classification des Roches Éruptives, p. 30.

[2] ROSENBUSCH: Massige Gesteine, p. 461. In this connection see TURNER: Geology of the Sierra Nevada, Sixteenth Ann. Report U. S. Geol. Surv., Pt. I, p. 737. Granulite (M. Lévy) is synonymous with aplite (Rosenbusch). Rosenbusch regards aplites as typically dike rocks, yet recognizes their occurrence as acid border phases of granite intrusions. *Ibid.*, p. 65.

At several localities the granulite can be followed from the contact and can be seen to pass gradually into the ordinary granite-gneiss. The changes on passing from the contact are as follows: (1) The rock becomes coarser, loses its granulitic structure and assumes a granitic structure. (2) The garnet disappears, biotite becomes abundant and is accompanied by the ordinary accessories of the granite-gneiss, titanite, magnetite and apatite. (3) Small grains of granophyre and microperthite

FIG. 4. Granulite (×18).

appear. These are common among the feldspars of the granite, but are wholly lacking in the granulite. Of these characters the granulitic structure and the presence of garnet extend farthest from the contact and often at a distance of many yards the richly biotitic granite-gneiss becomes garnetiferous and shows a decidedly saccharoidal texture.

Bands of granulite occur interbedded with or cutting across the schists near the contact. These bands are often less than an inch in thickness, and may connect with the main mass of the

granulite. A few of the smaller bands contain much muscovite and are well foliated. The granite-gneiss sometimes assumes a granulitic facies about inclusions. A good example of this occurs at one end of the Benvenue quarry, west of the river. A fifteen-foot mass of schist is caught in the granite-gneiss, which is dark gray and thick-bedded, but at the contact with the schist-inclusion changes to a fine-grained, white granulite with minute scattered flakes of biotite.

The eruptive nature of the granulite is clear. It cuts across the bedding of the surrounding schists ; it sends apophyses into them ; it holds inclusions of them. That it forms one geological body with the granite-gneiss is shown by its gradual passage into the latter at several points. It is not a crushed granite, as its position about the border of the granite and the absence of any microscopical evidence of crushing would show. It is an example of original endomorphic contact-metamorphism of the granite-gneiss,—more acidic and finer grained than the main body of the rock. The fineness of grain and the granulitic structure may be due to more rapid cooling of the magma in the neighborhood of the contact, though there is no reason why the conditions and consequently the structure of the granite-gneiss should be different at these points from what they were about the whole border of the granite. The more acidic character of the rock at the contact has not been satisfactorily explained. Similar phenomena have been observed elsewhere,[1] notably about some of the granite intrusions of France.

Besides the contact granulite described above, granulite occurs in three distinct forms. It occurs (1) as bands, generally not over a foot in thickness, cutting the granite-gneiss in or across the foliation and often becoming coarser and somewhat pegmatitic. In many cases these bands appear to grade somewhat abruptly into the surrounding rock. They are in a sense later than the granite wall-rock and may mark a closing stage of igneous activity, before the granite had fully hardened. It

[1] ROSENBUSCH, Massige Gesteine, p. 65. References to articles by BARROIS on several of these granites are given on p. 14.

occurs (2) as a white, fine-grained granulitic portion of some of the pegmatites. (3) One or several dikes of gray granulite cut the dark gneisses which occur associated with the granite-gneiss along its northern border (Map, 5). Their position is shown on the map. Each of these varieties has its own peculiarities and all differ from the contact granulite. They are probably all later than this last and are merely mentioned here for the sake of completeness.

5. *Darker and more foliated granite-gneiss.*—Along the north-eastern side of the granite-gneiss area is a belt which has already been noticed, in which the granite-gneiss alternates with schists and with dark, more or less hornblendic gneisses and amphibolites. This area is indicated on the map. Associated here with the granite-gneiss and with these other rocks is a third type, in a way intermediate, yet more closely related to the granite-gneiss. These last rocks are darker and more foliated than the granite-gneiss. They are frequently marked by lenticular-linear white patches, up to a third of an inch in thickness, composed of an aggregate of feldspar grains. From this character they may be named "spotted-gneiss." They agree microscopically in structure and in mineral composition with the granite-gneiss. There are only two differences: (1) an increase in the amount of biotite and, as a consequence, a better developed foliation, and (2) the presence in some cases of hornblende. Sometimes they show microscopical evidence of crushing. They form eruptive contacts with the schists which are cut by the granite-gneiss.

The relations of the spotted-gneiss and the amphibolites are not wholly clear, and these relations are probably different in different cases. The two rocks are distinct petrographically. The contact between the two is an eruptive contact. If the amphibolites are older—and their stronger banding and foliation might well suggest as much—it matters not to the understanding of the granite-gneiss whether they are of igneous or sedimentary origin; they are in either case earlier rocks cut by the granite-gneiss. But in many cases they are probably later.

For eruptive amphibolites occur abundantly in the schist and presumably sedimentary gneisses outside the granite-gneiss area, and at one point within the granite-gneiss (Map, 6) banded amphibolites occur grading into massive hornblende-gabbro, and this basic rock becomes finer grained toward the contact where it cuts across the foliation of the granite-gneiss. Some of these amphibolites, then, are certainly younger than the granite-gneiss and cut it. Some may be older than the granite-gneiss.

The relation of the spotted-gneiss to the more ordinary granite-gneiss is not altogether clear. In some cases parallel bands of the two lie in sharp contrast. Again within limited areas a complete series of intermediate rock types occur. The spotted-gneiss seems to be a somewhat more basic rock derived from the same magma as the granite-gneiss. In part, however, it looks as if the two were not strictly contemporaneous. The spotted-gneiss may have been intruded into the granite-gneiss, or *vice versa*, although both find their origin in the same molten body and were the products of a single igneous intrusion.

LEWIS G. WESTGATE.

SOME NOTES ON THE LAKES AND VALLEYS OF THE UPPER NUGSUAK PENINSULA, NORTH GREENLAND[1]

INTRODUCTORY STATEMENT

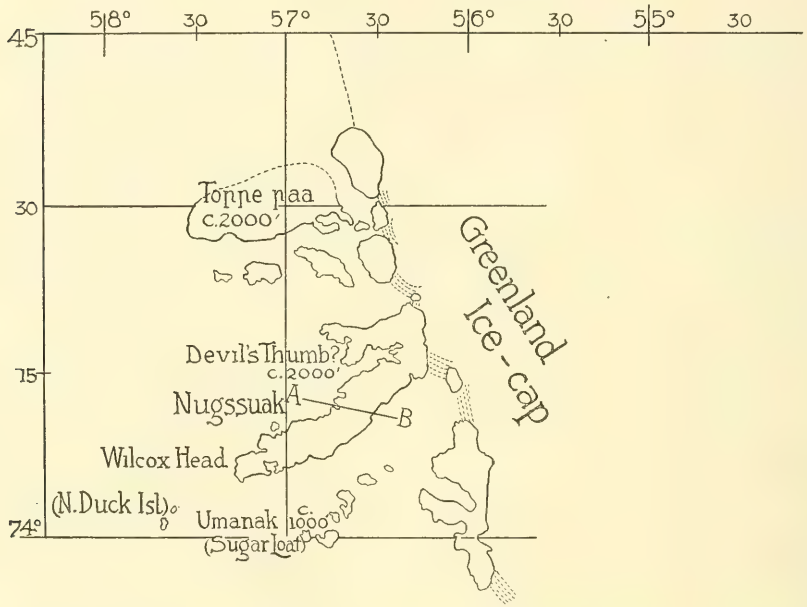
The Upper Nugsuak peninsula is located in north latitude 74° 5′–15′; is 25 to 30 miles long, averaging from four to six miles in width, and has a due southwest trend with the general coast line of Greenland. This part of the coast is characteristically rough and rugged. The marginal strip — at present ice-free — is intersected by numerous fjords, which, in many cases, penetrate to the very edge of the ice-cap, cutting the uncovered land into numerous islands and peninsulas. A considerable part of the uncovered lands is occupied by lakes.

The peninsula is limited on its north and south sides, by fjords descending to depths of not less than 300 to 500 fathoms, and varies in elevation up to nearly 3000 feet. The hilltops have a general elevation of 1000 to 2000 feet. Its surface is a very rough and irregular one; is cut up by a network of deeply incised valleys, the seaward extension of which add to the ruggedness of the coast line.

The general appearance of the inter-valley areas — hills and ridges — is that of a well rounded moutonnée form, which prevailingly show among the lower hills a highly polished surface, while the higher peaks are as uniformly angular, and are very much less subdued topographic types. Some of the valley slopes are steep, often times precipitous, often with large talus

[1] The writer wishes to express his indebtedness to the Cornell University Expedition of 1896, under the directorship of Professor R. S. Tarr, and of which the writer was a member, when this work was made possible. Further acknowledgments are due Professors R. S. Tarr and A. C. Gill, and Messrs. E. M. Kindle, J. O. Martin and J. A. Bonsteel for valuable aid and suggestions — especially Professor Tarr, who kindly read and criticised this paper in manuscript.

heaps at their bases. The slopes have been trenched and furrowed by running water derived from the melting ice and snows. The scarred and shattered surface everywhere testifies to the great rapidity of frost action. The results of glaciation are conspicuous over all its parts, attesting the fact that the ice-cap has over-ridden its entire surface at some previous time. Remnants of local glaciers still exist among the higher peaks of its north-



ern border. Bowlders are abundant, while the paucity of till is quite marked.

Owing to much variation in texture, the intimate relationship of rock structure to topography is well marked, as shown in the case of the dikes of basic rock — diabase (?) — found cutting the gneiss in various directions. The gneiss has been intricately folded and contorted.

LAKE CLASSIFICATION

No large lakes are found on the peninsula. The basins vary in size from one and a half miles in length down to the merest

pool. The largest water bodies are confined for the most part to the large valleys; but many tarns are scattered over the higher lands. Both types are, with one or two possible exceptions, true rock-basins, since they are entirely surrounded by rock in place; for there is rarely enough till for a dam. Based primarily on origin, the lakes are grouped under "Rock-basins due to glacial origin," and on position, are further grouped as (*a*), highland, and (*b*), valley lakes.

ROCK-BASINS OF GLACIAL ORIGIN

The highland lakes.—On account of their salient features, not all the highland lakes can be ascribed as the direct products of glacial erosion; but it is certain that all of them owe their origin, either entirely or in part, to glaciation. Therefore, since this class is in part directly and in part indirectly the products of glaciation, and since no differentiation of those that are ice-scoured basins from those that are perhaps only partially due to glaciation, can be effected, they are both grouped as highland lakes of glacial origin.

This entire group of lakes is composed of small tarns and pools of very shallow depth. Their distribution is apparently controlled entirely by the weaker rock structure. Where the joint planes were numerous and intersected, tiny lakes were often found. Generally, the larger highland basins were found developed in the direction of the strike of the gneiss, and had resulted from the removal of the softer layers of gneiss, by some process of erosion. Still others were observed where these planes of weakness were not apparent, but, in some cases, could probably be ascribed to the result of chemical or mechanical weakness, due to mineral distribution. The lakes are prevailingly irregular in outline, and contain varying amounts of weathered débris scattered over the bottoms of their basins, which is very probably due to recent action.

Their size, distribution, position and intimate relationship to rock structure, and irregularity of outline are sufficient evidence of their having resulted, in part, from differential atmospheric

erosion. Scarcely any doubt exists against the large share of these tarns having resulted directly from differential ice scouring along the line of weaker rocks. In other cases, however, the basins have been more or less modified by the ice advance, which served to remove the preglacial decay, resulting in some instances, in a probable deepening from this cause.

Evidence has been brought forward by others, proving that not all trace of minor preglacial form was destroyed by the ice advance over portions of this and the Baffin land coast. Furthermore, that in its advance, all the preglacial decay was not removed, but that a somewhat roughened and irregular surface resulted from such action, mostly along the lines of rock weakness. To the combined action, therefore, of differential preglacial weathering and ice erosion, along the lines of weak structure, are due most, if not all, of the group of highland lakes.

Concerning the origin of this type of lake along the Greenland coast and other similarly glaciated lands in the arctic latitudes Professor Tarr says:[1]

> It is noticeable near Cumberland Sound, as well as in Turnavik, and in Hudson's Strait, and indeed in Greenland, that there are many basins of small size, surrounded entirely by rock. While some of these have no doubt been scoured out by differential ice erosion, the position of many of them along the lines of weaker rocks, indicates that they represent differential preglacial weathering. The advance of the ice in these cases has served to remove the

[1] TARR, R. S.: Amer. Geol. 1897, Vol. XIX, pp. 195, 196.

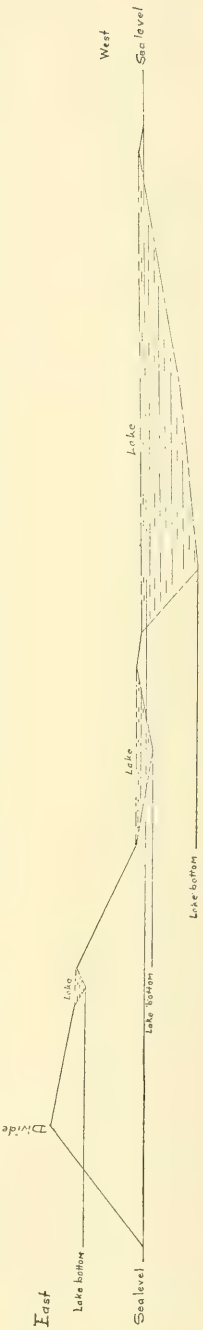


Fig. 1. Profile of valley marked AB
Scale 1" = 1/100 inches.

decayed rock, and perhaps to deepen the depressions formed by this action, though ice erosion would not in this case be the prime cause for the basin.

These [rock-basins] seem to be depressions caused rather by preglacial decay than by glacial erosion. They are often so small and bounded by walls so angular that origin by ice scouring seems impossible.[1]

The valley lakes.—The line, marked "AB" on the map, indicates the position of one of the largest valleys on the peninsula, with seaward termination on the east and west sides, and is from three and a half to four miles in length. Fig. 3 shows cross-sections, with reference to sea level, of the east and west ends of this valley. "A" was sketched at a point in the valley 165 feet above sea level, while "B" is only 15 feet above. Neither of these has been platted to any scale. A glance at the two is sufficient to note the contrast in outline of the two ends of the valley. The south end, A, is filled in on all sides to an unknown depth with perfectly angular blocks of large dimensions. This difference in valley width for the two ends is due, probably, in a great measure, to preglacial conditions. It is more than likely, that the preglacial divide was located near the south end of the valley, with its western end farther down stream, and therefore wider. The west end of the valley is fully three fourths of a mile wide, with inclosing walls rising 1000 feet and more above the bottom, sloping at a steep angle—less than 45°.

The valley further holds the largest lakes distributed along any one of the valley bottoms (see Fig. 2). Careful soundings were made of all the lakes located in this valley, and two showed their bottoms to be considerably below sea level. The position in the lakes where soundings were taken are marked on Fig. 2. After the sounding data were obtained, several possibilities naturally suggested themselves to account for this condition, in the lakes. A close examination of all the conditions, however, resulted in the elimination of all save one of the possibilities. Stream erosion with subsequent depression is eliminated on the ground of extreme irregularity of valley bottom. On the north and near the west end of the valley, the attitude of the strata is

[1] *Ibid.*, Bull. Geol. Soc. Amer. 1897, Vol. VIII, p. 255.

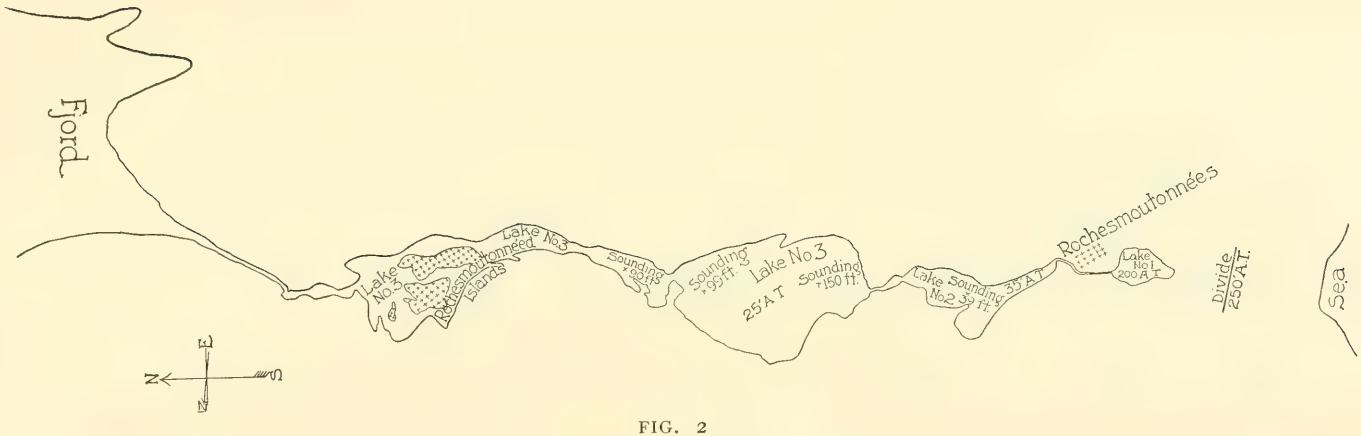


FIG. 2

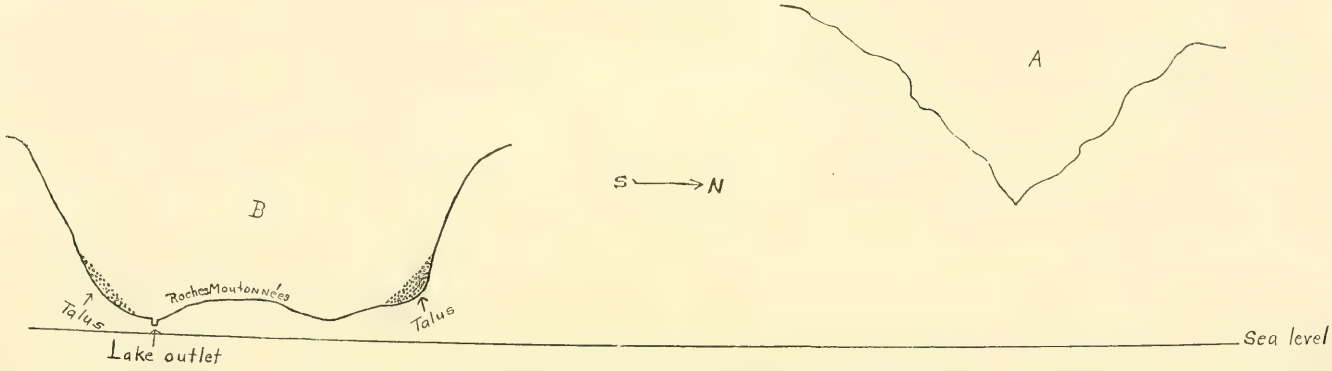


Fig. 3. Cross-section of valley 'AB'.

A = E. end.

B = W. end.

that of an overturned fold, whose axis is at right angles to that of the valley. The position of the strata proved that at no point could the valley owe its origin to folding. Rock structure and position were also opposed to origin by differential weathering. The tracing of the same and equivalent strata on the two sides of the valley would preclude faulting. Damming by deposition of morainic material is untenable, since no moraines of any extent occupy any portion of the valley.

The only other possibility to account for these lakes is that of "*ice erosion.*" A brief description of the lakes in this series, with the closely associated glacial phenomena, will best show the evidence for their glacial origin.

The first lake is the only one of this series with bottom above sea level. It is located 60 feet below the valley divide and 165 feet above the surface of the middle lake. It is more or less saucer-shaped in outline, and is, with the exception of the east side, entirely inclosed between highly polished and striated moutonnée forms.

The middle lake, marked lake No. 2 of Fig. 2, lies immediately against the high, precipitous south wall of the valley, and inclosed entirely by moutonnée forms on its north, south, and west sides. It is entirely surrounded by rock in place with its bottom 39 feet below sea level. The moutonnée forms on the north side of the valley are highly polished and planed, with glacial grooves and striae greatly intensified, reaching from the lake's surface up to an elevation of 100 feet. These are coincident with the trend of the valley.

The space between the middle lake and lake No. 3 of Fig. 3, is occupied by moutonnée forms of well-rounded outline and slight elevation. Lake No. 2 drains into lake No. 3 through a rock channel some 50 yards across and about 100 yards long, carved between the close-lying moutonnée hills.

The lake occupying the west end of the valley lies, for most of its length, immediately against the high, precipitous north side. It is something over a mile in length, very narrow, and quite irregular in outline, closely resembling a stream. It is

15 feet above sea level, and in its deepest part—near its head—is 150 feet below sea level. Perfectly developed glacial grooves and striae, with direction coincident with the axis of the valley, extend for quite a distance along the south border of the lake. The outlet channel is cut into solid rock, and averages from four to five feet in depth, with a U-shaped cross-section. The overflow passes over a low point in the divide between the lake and fjord on the southwest side of the valley. The divide is highly glaciated, and stands 25 to 50 feet above the lake level. As can be seen from Fig. 3, the portion of lake near the outlet is dotted with moutonnées rising to a slight elevation above the waters and forming a group of small islands in the lake. Bowlders of varying dimensions are found poised in various positions over the tops of nearly all the largest roches moutonnées in this valley. It will be further observed that the valley axis, AB of map, is approximately coincident with a westward advance in the general glacial movement over the peninsula. Further, that the largest and deepest water bodies are located in the northwestern portion of the peninsula, which portion is shown in a subsequent part of this paper to have been subjected to a period of more or less intense local glaciation. On the high hilltops forming the southwestern limits of the valley are found remnants of once larger local glaciers.

As a class, the valley lakes observed on the peninsula, range in size from something over a mile in length down to the smallest size basin. In outline, some were saucer-shaped—width and length about equal—but generally the length greatly exceeded the width, and when so found were invariably characterized by irregularity of outline. They varied from a few feet to 150 in depth, and in all cases their circumferences were marked by rock in place, proving them to be true *rock-basin* lakes. With but few exceptions they are prevailingly shallow and filled, more or less around their edges, with rock fragments derived from the valley sides, due to shattering by frost. Approximately eight to ten feet above summer water level and along the edges of parts of a few of the larger lakes were noted slender but perfectly formed

beaches. These may represent storm levels, or they may be the result of climatic changes. While the valleys probably cannot in all cases be ascribed to the same cause, the lakes associated with the valleys are, apparently, the result of differential ice erosion, and are true rock-basins, since they are walled in by rock *in situ* on all sides.

Dust wells and pools on the ice-surface.—The marginal surface area of the glacier ice was found dotted with numerous circular holes, varying from a quarter of an inch to several feet in diameter, and averaging probably several feet in depth. These were filled nearly to their tops with water, and their bottoms were invariably covered with a thick layer of dust. Professor Barton[1] has described the same condition to the south of this locality in the Umanak district, where he states, that the pits are confined to a marginal zone of about one mile in width, beyond which, and towards the interior, the ice surface becomes comparatively smooth. Professor Chamberlin[2] has observed the same conditions farther north along the west coast, and has fully discussed their origin in a previous number of this JOURNAL.

Other larger pools were seen. Professor Tarr[3] noted an especially large one, occupying a depression in the ice, of about one quarter of a mile in length in the direction of its longest axis, very shallow in depth, and revealing clear smooth ice, with no sediment over its bottom. No observation was made concerning its outlet, and Professor Tarr states that the pool probably represents a case of differential meeting.

Lakes due to other causes.— Along the ice margin, lakes were found, in places, formed by the usual ice marginal processes. A majority of these marginal lakes are due to a walling in of the numerous depressions of the extremely irregular surface of the peninsula, by the more or less steep ice-front on one side, and the slopes of the depressions of the land on the other. Each of

[1] Op cit., p. 216.

[2] JOUR. GEOL., Glacial Studies — Greenland, IV, Vol. III, 1895, p. 215.

[3] Communicated by letter to the writer.

these was fed by a marginal stream flowing along the ice front, which was, in turn, made up from the numerous smaller streams flowing off of the ice at its front. In some instances the lakes had been recently drained revealing heavy and conspicuous silt deposits, which necessarily were irregular in position, as is characteristic of marginal lakes. Some were found draining through tunnel outlets in and under the ice.

Morainal formed lakes, both by means of the masses ponding back the waters, and as kettles occupying the depressions in the morainal accumulations, were not uncommon.

Lakes noted at other points.—Rock inclosed bodies of water similar to those on the upper Nugsuak were noted at the following points: Turnavik Island, off the middle coast of Labrador; Big Savage Island, Hudson Strait; Icy Cove, the extreme southern coast of Meta Incognita; Niantilik, Cumberland Sound; and at several places along the Greenland coast to the south of the Upper Nugsuak peninsula. So far as observation extended their origin and development have been essentially the same.

At Niantilik a large number of typical rock-basins, resembling in every respect the Nugsuak lakes, were observed. Where studied, these were found developed in true strike valleys, and in case of the larger ones, roches moutonnées islands of slight elevation and formed by the hard layers of steeply tilted gniess were found. The character of these lakes left no doubt as to their being true rock-basins formed in part by ice erosion. Their entire circumferences were in many cases encircled by rock in place.

THE VALLEYS

No grouping of the valleys according to direction could be effected, since they were found trending with all points of the compass. An apparent series of major valleys were observed, cutting the peninsula in a direction varying from an almost east and west course to one at nearly right angles to this, which invariably had a seaward termination.

In a very general way, the larger valleys are best described as being very deep and broad, somewhat U-shaped in outline.

There are wide variations, however, from the steep sided and precipitous profile to that of considerably gentler slope. Frost action has wrought widespread results on the original glacial outlines of this form, resulting generally in a modification tending toward a less precipitous outline.

It has already been stated that numerous dikes of a basic eruptive rock, probably diabase, are found cutting the gneiss in an approximately vertical attitude. The basic dike rock of the peninsula has yielded more readily to the attack of the atmospheric agencies than the inclosing gneiss. Subsequent ice advance removed most of the residual decay, resulting in some instances, in the ice eroding considerably below the line of actual decay, determining thereby one set of the major valleys. The U-shaped outline is especially applicable to this type of valley.

Similar conditions apparently prevailed at Turnavik, Labrador, as on the Nugsuak. The rock is a coarse porphyritic gneiss cut by dikes of a basic eruptive, many of which have been eroded to a depth of some 20 to 25 feet by the ice, and in some of which residual decay was still to be seen, indicating a greater preglacial decay of the dike than country rock.

In the Umanak district of North Greenland, Professor Barton,[1] observed that the dikes of eruptive rock had not been eroded below the level of the inclosing gneiss, but instead, they were found, in some instances, standing "out in relief above the gneiss."

No petrographic study has been made of the rocks in the localities mentioned above, hence it would not be safe to say whether the difference could be accounted for on lithologic grounds, or whether it is due to a difference in glacial conditions.

A second type of valley, but of minor importance, on account of slight development, was noted, the origin of which was traceable to the etching out of the softer rock layers in the highly tilted strata by differential atmospheric weathering, and can therefore be classed as strike valleys.

Subsequent to the period of widespread general glaciation,

[1] BARTON, GEO. H., Technology Quarterly, 1897, 10, 236, 237.

the northern ends of the valleys have undergone considerable modification from a period of local glaciation, which is now confined to the northern side of the peninsula, and in its last declining stage Owing to the work of local glaciation, more or less contrast is observed in the topography of the opposite ends of the approximate northwest-southeast trending valleys (see Fig. 3). Glacial filling, principally bowlders with some till; abundance of typically developed roches moutonnées, glacial grooves, striae, planing and polishing, conspicuously characterize all of the major valleys.

A large number of the major valleys were associated with dikes of basic rock. So far as studies were extended, the mass of fact pointed to the conclusion, that this type of valley was due to differential preglacial decay with subsequent ice erosion. The entire set of major valleys, everywhere viewed on the peninsula, are distinctly preglacial; and while their origin was not apparent in every case, they have all suffered considerable subsequent modification from ice erosion.

A parallel is probably found in Canada, where Dr. Robt. Bell[1] has observed greenstone dikes protruded into granites. The dikes have subsequently been worn out and at present form valleys occupied by lakes and streams.

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[1] BELL, DR. ROBT., Bull. Geol. Soc. Amer. 1894, V, 364.

AN ATTEMPT TO FRAME A WORKING HYPOTHESIS OF THE CAUSE OF GLACIAL PERIODS ON AN ATMOSPHERIC BASIS

(Continued)

SPECIAL APPLICATION OF THE HYPOTHESIS TO THE KNOWN GLACIAL PERIODS

It now remains to specifically apply the hypothesis to the recognized glacial periods. At present only those at the close of the Paleozoic and Cenozoic eras are sufficiently determined to require discussion.

The mapping of the Pleistocene glacial deposits is sufficiently complete to show their great features, and reveals a strong development in the northern hemisphere, and at the same time a quite peculiar localization. The analysis of the deposits has progressed far enough to show that the glacial period was marked by pronounced oscillations of both the major and the minor kind. Interglacial epochs of a declared character may be assumed to be fairly demonstrated, while the glacial epochs themselves were attended by rhythmical stages of progress, as most pointedly brought out by recent detailed field work in the Mississippi and St. Lawrence valleys, notably that of Mr. Leverett and of Mr. Taylor. These rhythmical features are made the subject of a special discussion by Mr. Taylor in a paper entitled "Moraines of Recession and their Significance in Glacial Theory."[1]

To be really applicable to Pleistocene glaciation a working hypothesis must therefore not only postulate agencies capable of producing a glaciation covering the American plains down to

[1] Jour. Geol., Vol. V., No. 5, 1897, pp. 421–465. See also "The Great Ice-Dams of Lakes Maumee, Whittlesey, and Warren," American Geologist, Vol. XXIV, No. 1, July 1899, pp. 6–38, and the review of this paper by Mr. Gilbert in the last number of the Jour. Geol.

37° north latitude, and mantling also the plains of middle Europe and high altitudes quite generally, but it must assign agencies for the oscillations which attended it.

General cause.—The atmospheric hypothesis finds a general cause for the Pleistocene glaciation in that notable extension and elevation of the land which reached a climax near the close of the Pliocene period. It is not, however, through its direct topographic influence that this was accomplished, though this may have been incidentally tributary, but through its effects on the constitution of the atmosphere. The recently named Ozarkian or Sierrian period embraces the specially effective stage of this great land area, and it is with much pleasure that I support the emphasis laid upon the significance of this period by Professor Le Conte in his paper in the last number of the JOURNAL,[1] though I interpret that significance in different terms. The wide extent and high elevation of the land at that time are so strongly set forth by Dr. Le Conte as to leave no need for additional emphasis here.

A rude estimate of the land area in Middle Tertiary times, when the climate was mild far to the north, gives about 44 million square miles. A similar estimate for the Ozarkian or Sierrian period gives about 65 million square miles, while the received estimate of present land is about 54 million square miles. Taking the Middle Tertiary area as a basis of comparison, the land was increased in the Ozarkian period about 47 per cent., and afterwards fell off to the present area, which is 23 per cent. greater than that of the mid-Tertiary. It is probably conservative to estimate that the average elevation of the Ozarkian land was at least two or three times, perhaps three or four times, as great as that of the mid-Tertiary. Combined in the light of the suggestions previously made regarding elevation, these indicate a very great change in the effective contact of the atmosphere with the earth. If we measure the actual contact by the surfaces of the grains, pores, fissures, and minute crevices with which the air and the atmospheric waters come in contact

[1] Pp. 525–544.

—and this is the true contact area—the increase will appear impressive.

As in other cases, there was here also a self-accelerating action. As land was elevated, its underground water level was at first carried up measurably with it and lay near the surface. Trench-cutting accompanied it, to be sure, but at a slower rate. As the declivity increased the cutting and transportive power of the drainage increased, and as the dissection of the land proceeded, the water level was lowered and the effective zone of atmospheric contact augmented. The very process of degradation, up to a certain stage, increased the facilities for the chemical action of the atmosphere. In general it may be observed that degradation reacts upon itself favorably for a time. The cutting of certain of the western plains into "bad lands" and the gullying of the cultivated fields in certain parts of the southern states are striking examples of current self-accelerating processes of the more mechanical sort.

Concurrent with this increase of the atmospheric contact-area on land there was a reduction of sea surface, the habitat of lime-secreting life, and, *nota bene*, an almost complete obliteration of the epicontinental seas and sea-shelves which were the parts of the sea bottom that were by far the most prolific in carbonic-acid-freeing marine life. Shallow-water marine life must have been very generally driven down on the abysmal slopes and on to such limited deeper shelves as may have been brought within reach by the lowering of the seas. The consequent lessening in the rate of freeing of carbon dioxide is assumed to have been great, and this coöperated with the accelerated consumption on the land to hasten the depletion of the atmosphere.

Besides this, when any appreciable reduction of temperature followed these coöperating agencies, it tended of itself to check the lime-secreting life of the ocean, and at the same time to give the oceanic waters greater absorptive power and less dissociative activity, thus calling into operation a group of secondary agencies which intensified the effects of the primary agencies.

Now the task assigned this remarkable combination of agencies is not a formidable one. If we take the largest of the current estimates of the present atmospheric content of carbon dioxide, viz. .06 per cent. by weight (comparable to .04 per cent. by volume), the mid-Tertiary atmosphere should have contained .15 per cent. to .18 per cent. of carbon dioxide, and that of the glacial period .03 per cent., following Dr. Arrhenius' estimates. That is to say, for the reduction of the carbon dioxide of the Tertiary atmosphere from the assigned .15 per cent. or .18 per cent. to the assigned .03 per cent. of the glacial period, we have an estimated increase of land area of 47 per cent., and an increase of elevation of 100 per cent. or 200 per cent., and perhaps more. To produce the present amelioration we have a falling off of about one half in each of these items.

Numerical data, which will be given later, indicate that something like $\frac{1}{2000}$ of the carbonic acid of the air is now taken out annually. If the same amount is returned, the constitutional status is preserved. But if the foregoing agencies that coöperated in late Pliocene and early Pleistocene times to disturb the balance between removal and return were effective to no more than 10 per cent. of the total rate, it would have been capable of reducing the assigned mid-Tertiary content of .18 per cent. carbonic acid to the assigned glacial content of .03 per cent. in 50,000 years. It is not, of course, supposed that the rate would be constant as the state of enrichment changed, and note of this will be taken later, but the computation serves to show how effective a disturbance in the relative rates of supply and removal becomes when such action bears so high a ratio to the total mass of carbon dioxide in the air. It may also serve to show that the hypothesis is assigning agencies whose supposable quantitative competency is abundantly adequate to the results imputed to them.

ASSIGNED CAUSES OF GLACIAL OSCILLATION

It has been already noted repeatedly that the assigned causes of glaciation are self-accelerating in certain significant

phases. The salient effect of this, reasoning on general principles, must be to push results to an extreme from which reaction is inevitable. Let us consider this in detail. It is thought that there were three dominant agencies concerned in this, modified by several subsidiary ones.

1. A necessary consequence of the accelerated rate of transmission of carbon dioxide to the sea, combined with a slackened rate of release in the sea, was an accumulation of oceanic carbon dioxide. The primary form of this was an increase of the carbonates.

2. The cooling of the sea waters which attended the process reduced the dissociation, and hence the carbonates were more nearly full bicarbonates than before. *There were, therefore, not only more carbonates, measured by the bases, but they carried more carbon dioxide in proportion to the bases.*

3. With the growth of the snow-fields attendant on the progress of glaciation, there was an increase of reflection of the sun's radiation and a reduction of its absorption. Computation shows that the albedo is an important factor.

Subsidiary to these there were the following:

4. There was an increase in the absorption of carbonic acid in the ocean, resulting from the lowering of the temperature. This, however, was offset by the declining partial pressure of the carbon dioxide in the air, and, as the two seem to be of the same order of magnitude, they may be set aside for the present.

5. With increasing cold there was a less rapid decay of organic matter and a less complete release of carbon dioxide. Over against this, however, there was a reduction in the amount of carbon locked up in living organic matter. It is difficult to form a trustworthy estimate of either, but it may be provisionally assumed that they belong to the same order of magnitude and may be set aside together. At any rate, any residual difference would not apparently be a notable factor.

6. The majority of chemical authorities state that the solubility of calcium carbonate in water saturated with carbonic acid increases with a lowering of temperature through ordinary

ranges. Unfortunately there is not complete unanimity on this point. But, if this be true, as the temperature fell the solvent action of the carbonic acid of the land waters upon the limestone was increased. Over against this was a probable reduction of the action of organic acids. Probably the decomposition of the silicates went on at a lower rate, but, as it was much less than one fifth of the whole action, its reduced rate is not very material here.

As the carbonic acid of the air was diminished, its action on the land surface declined—though not at a proportional rate—but long before it could offset the enlargement of the contact area aided by the sea action, glaciation would be far advanced, if the previous estimates hold good.

Setting aside, as being measurably balanced, or as being of minor or uncertain value, all but the first three items, which are clearly factors of great potency, we find at first a strong disposition toward the acceleration of the depleting process.

But this, although a pronounced influence in the early stages of refrigeration, could not continue indefinitely, for the process involved the conditions of its own arrest.

The arrest of the depletion and the inauguration of the reaction.—With the development of glaciation, the agencies that tended to counteract atmospheric depletion received a powerful ally in the ice-sheet itself. The spread of the ice over the surface prevented further effective weathering of the area so covered and correspondingly arrested atmospheric depletion. The total area covered by glaciation at its maximum was probably not far from 8 million square miles, or nearly 15 per cent. of the land surface.

Besides this, the area outside of that actually covered by the ice-sheets was probably affected by prolonged freezing during the winter stages, and was perhaps to some extent permanently frozen beneath the surface, and this arrested solvent and chemical activity. If the modest figure of 5 per cent. be assigned for this supplementary effect, 20 per cent. of the functional area would be withdrawn from action. Whether this numerical estimate be correct or not, it may be assumed that if a given amount

of withdrawal, combined with associated agencies, were not sufficient to arrest the progress of glaciation, the glaciation would have continued to extend itself until the point of balance was reached. It is, perhaps, not too much to assume that the extension of glaciation and its concurrent agencies mark in themselves the measure of preponderance of the depleting agencies at the stage when glaciation began. That is to say, after the depleting agencies had brought the air's carbonic content down to the point at which the glacial centers were inaugurated, these agencies were still preponderant over the repleting agencies to some such extent as 20 per cent., more or less.

While it does not seem necessary to our general purposes to consider the associated agencies of arrest, if these views be correct, they possess an interest of their own, and may be mentioned briefly.

With little doubt the lowering of the temperature lessened the rate of decomposition of the silicates, though frost action aided in disaggregating them mechanically and in thus increasing the atmospheric contact. On the other hand, while the authorities are not altogether agreed, the weight of the latest opinion supports the view that the limestones would be dissolved by cold water saturated with carbon dioxide faster than by warm water, other things being equal. The cold waters would quite certainly contain more absorbed carbon dioxide than warm ones. Probably other things were not equal, for the vegetable action and the organic acids probably lent less and less aid as the temperature fell. It is not clear what the balance of these influences combined would be. Whichever way it leaned, it does not seem to have been of decisive moment.

As previously remarked, the progressive removal of carbon dioxide from the air reduced the amount of its action, but not proportionately. While this lessened the depleting action it does not seem to have reached decisive moment, at least not until a late stage in the process of depletion.

Meanwhile, in the ocean, conditions favoring reaction were

gathering force as the result of the processes in action there. The ocean was accumulating carbonates and augmenting their degree of bicarbonation with the increase of cold. Now it is obvious that if the loading of the ocean with carbonates were to proceed to the point of saturation, inorganic processes of precipitation and dissociation would come into play to an extent that must necessarily balance all further accessions of material. It does not appear, however, that there is enough, or even nearly enough, carbon dioxide in the air to bring about a condition of full saturation of the ocean with bicarbonates, even if it were all to take that form, and were to be conveyed completely to the sea. But the movement toward saturation should increase in some degree, probably small, the efficiency of inorganic agencies tending toward precipitation, although it could become notably effective only after prolonged accumulation.

The concentration of carbonates in the ocean was somewhat aided by the removal of water required to form the great ice-sheets. On a rather large estimate of the mass of the ice-sheets, this extraction might possibly reach 5 per cent. of the volume of the ocean.

There would probably be a progressive evolution of lime-secreting life adapted to the cooled waters, and this would increase the rate of carbonic release and contribute to a reversal of action.

None of these subsidiary agencies, nor all combined, seem to have been controlling factors.

It is notable that some of these subsidiary agencies, on both sides, are final in themselves and quite without retroactive possibilities. When once their work was done there was no resilience. It was quite otherwise with the ice mantling and the ocean loading. Far from being final, these contained in themselves the potentialities of reaction and gave vigor to the reaction when it took place.

Agencies that precipitated reaction.—When once the reactive agencies had reversed the relative rates of enrichment and

depletion and there began to be an increase of carbon dioxide in the air, the following influences would coöperate to hasten and intensify the reactive movement.

1. The dissociation of the second equivalent of carbonic acid associated with the carbonates of the ocean would be increased, and as the temperature rose from the diffusion of the freed carbon dioxide into the air this would be still further augmented by its own reactive effects. This is one of those interesting agencies whose effects at once become causes of further like effects.

2. The increased warmth would call forth more lime-secreting life in the ocean, and thus also hasten the freeing of carbon dioxide, and this again would react favorably on itself.

3. The increase of water from melting ice would somewhat extend the shallow-water zone and favor lime-secreting life. If the land were depressed by the load of ice, as some suppose, this would increase the sea area and favor lime-secreting life. With this may be associated the falling of the water level in the high latitudes (to which it had been drawn by the gravitation of the accumulated ice mass) and a corresponding rise of the water level in lower latitudes. Since the lower-latitude life is more abundant than the high-latitude life, and more effective in extracting lime, the shift would involve a gain in lime-secreting potency.

4. The increased decay of organic matter attendant on the warmer temperature would develop carbon dioxide; but over and against this must be set the increased carbon locked up in the augmented living matter. These, as before, are set aside, as perhaps mutually offsetting each other.

5. The increase of temperature arising from the preceding causes would increase the water vapor in the air and thereby add to the thermal capacity of the atmosphere, and this would react favorably upon itself and upon the other agencies favored by high temperature.

Thus the reaction once started would be self-augmenting,

until the fundamental conditions were changed or the reaction was checked by its own ulterior consequences. The sequences may be easily followed. The carbonates of the sea, which had been augmented during the epoch of glaciation were now diminished and limestone was more actively deposited. The ocean, previously fattened in carbonates now became lean. So also the carbonates themselves, that before were quite plump bicarbonates, now became degraded to a mixture of normal and acid carbonates. In short, the ocean holds less free and feebly-combined carbon dioxide and the air holds relatively more. As the ocean is now estimated to contain from eighteen to twenty-five equivalents of atmospheric carbonic acid in the free and feebly-combined states, a moderate fluctuation in its content would cover the full range of atmospheric variation required to produce the climates under discussion, according to Arrhenius. On the supposition that the glacial epoch was produced by a reduction of the carbonic content of the atmosphere to one half the present amount, it would only be necessary for the ocean to release 2 or 3 per cent. of its releasable carbon dioxide to restore the atmosphere to the present condition. If the ocean gave up 4 or 5 per cent. of its releaseable carbon dioxide the climate would be notably milder and more equable than the present. Assuming the correctness of Dr. Arrhenius' conclusions, it would seem from these considerations that there is nothing forced or violent in the supposition that an effective interglacial epoch might be brought about by the reactive agencies indicated.

Recrudescence of glaciation.—If the land area of the globe as a whole remained large and high notwithstanding such local depressions as have been attributed to the weight of the ice and the effects of low temperature; or, more precisely, if the atmospheric contact area remained large, the conditions for a renewal of glaciation would again prevail because the renewal of warm temperature, the enrichment of the atmosphere, and the depletion of the ocean would restore the original action. So soon as the ice had retreated from the land, the weathering of the

uncovered area would be renewed. This, of course, would begin so soon as the retreat began, and increase in a corresponding measure; but it is a slow process, while the reactions of the ocean are relatively rapid — indeed they should keep close pace with the rise of temperature which they induce. There should be no appreciable lag. After the retreat of the ice a new surficial factor would come into play, the sheet of drift spread over the surface. In so far as this consisted of undecomposable matter blanketing decomposable matter, it would interfere with the progress of decomposition, but in so far as it consisted of limestones and silicates ground to a flour and exposed to the atmosphere, it would facilitate chemical action and expedite a second depletion of the atmosphere and through it a second term of glaciation. Aside from the effects of this mantle of drift and such changes of topography as might have occurred, the conditions for the renewal of glaciation would be, so far as I see, as effective as they were at the outset. Assuming that they were equal to the preceding, a second glaciation equal to the first is to be postulated, and a corresponding reaction at length, as in the previous case, due to like agencies. Thus a series of glaciations and deglaciations should follow each other until the general causes lying back of glaciation had disappeared.

In so far as the land, on the whole, settled back toward sea level or was worn away, or, by any other agency, lost its degree of effective exposure to the atmospheric action, in so far the conditions of glaciation would disappear. Pursuing the normal history which follows a period of great land elevation, it is to be presumed that there would be a gradual reduction of the land surface and land elevation, and that hence the conditions productive of glaciation would gradually pass away. On such an assumption it is presumed that the recurrent glacial advances and retreats would become more and more feeble until the series vanished. Nominally, then, the glacial and interglacial epochs should form a rhythmical series declining from large oscillations at the maximum to lesser and lesser oscillations as the series

disappeared. This seems to correspond with the observed oscillation of glaciation in both Europe and America.[1]

INTERCURRENT AGENCIES

Without question the normal series of glacial oscillations just postulated would be subject to intercurrent influences which would be liable to disturb, perhaps quite seriously, its regularity and symmetry.

1. Any notable movement in the land which affected the sum total of the atmospheric contact area would disturb the symmetry of the series.

2. Any notable change in the original supply of carbonic acid through volcanic action or other agency would produce obvious modifications. The deformation of the body of the earth out of which the conditions of glaciation are assumed to have sprung would doubtless be favorable to volcanic action, and if this reached a degree of intensity sufficient to add appreciably to the carbon dioxide of the atmosphere, it would radically affect the ongoing of the process. That there was extensive vulcanism nearly or quite concurrent with glacial action has been urged by some geologists; indeed, glaciation has even been attributed to volcanic action.

3. The precession of the equinoxes has been regarded by many thoughtful students of glaciation as an influential agency. If affective, it would superpose a rhythm of its own upon the rhythm postulated by this atmospheric hypothesis. For specific illustration the extensive series of moraines which marked the later stages of the Wisconsin epoch of glaciation are referred by Taylor to precessional influence, while the Wisconsin glaciation itself would, under the atmospheric hypothesis, be referable to atmospheric depletion. The most serious question which here arises is the compatability of the prolonged period implied by Taylor's interpretation with the rate of reaction implied by the

[1] The Classification of European Glacial Deposits, JOUR. GEOL., Vol. III, No. 3, pp. 241–269, JAMES GEIKIE; The Classification of American Glacial Deposits, *ibid.*, pp. 270–277, T. C. CHAMBERLIN; editorial, *ibid.*, Vol. IV, No. 7, October–November 1896, pp. 873–876.

atmospheric hypothesis.[1] This will be more evident as we touch on the time rates.

4. The change in the eccentricity of the earth's orbit which Croll has made the foundation of his beautiful hypothesis of glaciation, if not found competent to produce general glaciation itself, might still be effective in producing climatic changes of less degree, and might superpose important modifications upon the series postulated by the atmospheric hypothesis. It may be remarked in passing, however, that the computed variations of eccentricity of distant periods of the past do not rest on so firm a mathematical basis as is currently supposed.

It is obvious that these and other possible agencies might work concurrently with the atmospheric influences, or antagonistic to them, in either case distorting and masking the normal rhythmical expression which a purely atmospheric series would assume.

DO THE TIME RATES FALL WITHIN WORKABLE LIMITS?

The working capabilities of a glacial hypothesis are somewhat severely conditioned by its time factors. It must not only present a satisfactory correlation between the time of occurrence of glaciation and that of the assigned cause, but the rhythmical action of the cause must be consonant with the rhythmical history of glaciation. That the Pleistocene glaciation followed the Ozarkian or Sierrian stage of elevation at an appreciable distance, I hold to be demonstrated by the relations of the glacial deposits to the eroded topography of that period. On the other hand, there is no evidence of a prolonged interval, geologically speaking. The atmospheric hypothesis demands that the accelerated erosion due to elevation (or rather to the dissection that followed elevation) should have continued long enough to remove about three times the present atmospheric content of carbon dioxide before glaciation could begin, following Arrhenius' computations. This removal could only be accomplished by the *excess* of consumption of carbon dioxide over supply and there is

[1] See GILBERT'S review in last number of this JOURNAL, p. 621.

reason to believe that the rate of supply from the interior was greater than the average on account of crustal disruption and volcanic action. There seems, therefore, little ground to think that the glaciation should have followed closer after the elevation than it seems to have done. It would seem rather that the hypothesis was happy in this time relation at least.

With most geologists, I doubt not, the chief question will be whether the postulated agencies could cause the glacial oscillations, involving the removal and reproduction of the ice, in large part or in whole, as rapidly as the field evidence requires. Present measures of glacial rates and times are quite uncertain but not indefinitely so. Some rude approach to their value may be attained. Recently expressed opinions regarding the time since the last ice retired from the site of Niagara River, and inaugurated the erosion of its gorge, lie between 7000 and 33,000 years, which we may average at 20,000 years. I place no special confidence in this figure, but it is rudely representative of the average order of magnitude of expressed opinion. This represents only a part of the time since the beginning of the deglaciation that removed the Wisconsin ice-sheet. According to Taylor's views it would be only a very small part. I doubt if any careful geomorphic geologist familiar with all the phenomena involved would seriously consider an estimate that made it much more than one half at the most; so that it would apparently not be straining the evidence to take 40,000 years as a rude measure of the time since the beginning of the retreat from the outermost moraine of the Wisconsin stage. However, this may probably be cut in half and halved again without over-straining the possibilities of the hypothesis.

This is the time of retreat. An interglacial epoch involves not only the time of retreat, but the time of interglacial mildness and the time of re-advance. The best specific data now available in America for estimating these elements are undoubtedly those afforded by the excavations about Toronto which have

been so fruitfully cultivated by Hinde, Coleman, and others.[1] (1) The time occupied in the ice retreat is there almost without record. (2) The duration of the mild climate is recorded in thirty-five feet of clays and sands. It is also implied in the time necessary for the migration of the Paw Paw, Osage Orange and other trees from more southerly regions to this rather northern locality, and also for the migration of the clams and other molluscs from the Mississippi waters to this rather distant region. Both of these migrations were probably rather slow processes. (3) The initiation of the returning cold is recorded in 150 feet of fine stratified peaty clays and sands. (4) Following this there was an unknown period occupied in the transition from the conditions of deposition, during which the preceding series had been formed, to the conditions of effective erosion which followed. To suppose that this transition was due to the removal of an ice-dam that had lingered in the lower St. Lawrence seems quite untenable for a long, mild period and a long, cool, but not glacial, period had intervened. It was probably due to the cutting down of the drainage outlet, or to a surface movement, or the two combined, and hence probably occupied an appreciable time. (5) There then followed a period of erosion comparable to that since the last ice invasion. Succeeding this came the re-invasion of the ice-sheet.[2] These data seem to fairly imply that the interglacial epoch represented at Toronto was several times as long as the postglacial epoch.

While nowhere else has so complete a record been found, many estimates of the differences of erosion of the several till sheets in the Mississippi valley, where the formations are well deployed and happily suited to such studies, have been made

[1] GEORGE JENNINGS HINDE: Glacial and Inter-Glacial Stages of Scarborough Heights. Can. Jour. 1878, p. 388 *et seq.*

A. P. COLEMAN: Am. Geol., Vol. XIII., February 1894, pp. 85–95. Ditto. JOUR. GEOL., Vol. III., No. 6, 1895, pp. 622–645.

[2] Canadian Pleistocene Flora and Fauna: Report of the Committee consisting of Sir J. W. Dawson (chairman), Professor D. P. Penhallow, Dr. H. M. Ami, Mr. G. W. Lamplugh and Professor A. P. Coleman (secretary), appointed to further investigate the flora and fauna of the Pleistocene beds in Canada.

by experienced glacialists, and their concurrent judgment is that the least of the notable interglacial intervals was at least two or three times as great as the postglacial interval. It would not be exceeding current judgment, therefore, to assign from 80,000 to 120,000 years as the duration of a typical interglacial epoch.

But in the interest of conservatism let the postglacial interval be taken at 10,000 years and the interglacial at 20,000 or 30,000 years. This seems to me excessively conservative. If the assigned agencies can affect a reënrichment of the atmosphere in carbon dioxide to an amount somewhat exceeding the present content and then again a depletion of one half within 20,000 or 30,000 years, the hypothesis will not be excluded by time limitations.

We have the following pertinent data based in part on Reade's[1] estimates of the present rate of removal of carbonates:

Total mass of the atmosphere	5×10^{15} tons
Mass of atmospheric CO_2 (reckoned by weight at .0006)	3×10^{12} tons
Total mass of CO_2 taken annually from the atmosphere	162×10^{7} tons
Mass of CO_2 consumed annually in original carbonation (reckoned by area at 20 per cent. of the land)	27×10^{7} tons
If reduced one half on account of the slower rate of decomposition of crystallines it will be 13.5×10^{7} tons, in which case the other half is to be added to the following item, if Reade's estimates are correct.)	
Mass of CO_2 consumed annually in forming bicarbonates	135×10^{7} tons
Time required at this rate to consume total atmospheric CO_2, assuming no return	1852 years
Time required at this rate, without return, to consume one half atmospheric CO_2 (the reduction requisite for glaciation.)	926 years
Time required to consume half the "free" and "loose" CO_2 of the ocean (estimated at 18 times that of the atmosphere) without return	16,668 years
Time required to consume half the CO_2 of the atmosphere and the ocean combined, without return	17,594 years

The last items which involve the reduction of the carbon dioxide in the ocean as well as in the atmosphere are not really

[1] Loc cit. on p. 569.

pertinent to the discussion, if the foregoing doctrine relative to the mode of action of the ocean during a glacial period is correct, for it is there maintained that the ocean does not give up its carbonic acid with increasing depletion of the atmosphere, but, on the contrary, increases its content. They have some interest, however, in connection with it and with other phases of the atmospheric hypothesis which the reader may possibly wish to consider. They also have some pertinency to the discussion of Paleozoic glaciation, to be taken up presently.

We are here concerned especially with the rate at which atmospheric carbonic acid may be consumed to the amount of one half the total content. For convenience, no account has been taken of the return of carbonic acid from the ocean or through organic action. We reach the rather startling result that if there were no return, the decomposing and solvent action on the present contact area would consume one half of the atmospheric carbon dioxide in less than 1000 years. This result, based on Reade's estimate, may be checked by independent computation on a more familiar basis and by different modes of computation. For example, by assuming the average rate of degradation of the land surface to be one foot in 5000 years, and that the carbonates constitute 15 per cent. of the material removed, one half of the carbonic acid of the atmosphere would be consumed in 1248 years, if there were no return; or in 1000 years if the degradation was one foot in 4000 years.

The actual depletion must, of course, depend upon the excess of this rate of removal over the rate of return. I have already endeavored to show that there was a very large fluctuation in the conditions that determined the relative rates of consumption and return, notably that the land of the Ozarkian time was more than 20 per cent. greater in area than the present land, and that its elevation was probably 100 per cent. or 200 per cent. greater at the maximum stage of protrusion. And this was correlated with coöperating conditions in the ocean. Both of these estimates, however, must be considerably reduced to give a safe measure of the area which was operative at the time of the

inter-glacial epochs, or at least some of them, for there is abundant evidence that the land was not then so greatly elevated as in the Ozarkian or Sierrian period.

Instead, therefore, of combining 20 per cent. increase of land area with 100 per cent. increase of elevation, and these with the coöperating 20 per cent. reduction of sea area, the destruction of sea-shelves, and the restraining effects of lowering temperatures, as we are entitled to in bringing down the rich Tertiary atmosphere to the lean conditions of the glacial period, let us content ourselves with some modest fraction of these intensifying combinations. If we only assume that the agencies of depletion were superior to the agencies of return by the amount of 10 per cent., the depletion requisite to bring on a glacial epoch, starting with atmospheric conditions like those of the present, would be effected in less than 10,000 years. If, therefore, we over-generously allow as much time for deglaciation as for reglaciation, an interglacial epoch might not require the operation of the postulated agencies for more than 20,000 years, so far as they themselves are concerned. The development of the ice-sheet might take more time, but we have little or no data for estimating this. If 10,000 years additional is allowed for this the total remains at the modest figure of 30,000 years.

It would not seem to be pushing the data previously given to extremes to postulate a larger percentage of difference between depleting and repleting agencies than 10 per cent., which would make the requisite atmospheric depletion possible in a shorter period. It is probably not extravagant to assume that the difference might rise to 20 per cent., in which case the requisite time would be brought down to extremely modest limits. It is difficult to see how anyone who studiously considers the phenomena of the Toronto interglacial epoch could assign to it a duration less than is compatible with these agencies, as here interpreted. It would seem, therefore, that the hypothesis is not excluded from the working category by inadaptibility to the time rates of the phenomena which it seeks to elucidate.

There is not likely to be any serious question respecting the

time rates at the other extreme, that is, that the agencies necessarily act too rapidly to correspond to the phenomena. Of course, in the final adjudication of the hypothesis, it will be necessary to show that its time rates not only might correspond to the time rates of the phenomena, but that they did so, but this is a labor of the future, and is obviously dependent upon a very notable extension of precise knowledge, which it is the purpose of the hypothesis to aid in calling forth. It is sufficient here to show that reasonable postulates, based on a reasonable estimate of the phenomena, fall within compatible limits.

T. C. CHAMBERLIN.

(To be continued.)

THE NAMING OF ROCKS

Introduction of new names.—In the early days of petrography it was supposed that there existed rock types as definite as mineral types. Following this hypothesis, a rock found which was different from any rock before described was immediately given a new name. This went so far that an altered rock was given a family name, as in the case of *diabase*, an altered dolerite. After some years a scheme of nomenclature was worked out which was supposed to be approximately complete. For a time subsequently, when a rock was discovered having a somewhat different character from previously known rocks, it was referred with modifying mineralogical prefixes to some of the so-called types.

A few years ago another period of name-giving was inaugurated. During this period, which continues to the present time, petrographers have introduced numerous new, independent names, both for long-known and for newly-discovered varieties of rocks. Since 1890 more than fifty new names have been added to the nomenclature of the igneous rocks, a larger number than young petrographers were obliged to know the meaning of before 1890. The stage through which petrography is passing is somewhat similar to that through which at one time paleontology passed. One might almost think that petrographers were seeking to find varieties of rock slightly different from those before known in order to give them new names.

Method in giving new names.—The method of petrographers in proposing names, so far as any method is discoverable, is to give an independent name to each rock which is slightly different from any previous rock found, without reference to any definite plan of nomenclature. The greater number of the names are not proposed to designate varieties which are subordinate to previously recognized kinds of rocks, but are names coördinate with those before used. In petrography, a binomial nomenclature thus far has not been generally adopted, and therefore it has

not been possible to drop the new name and place the thing referred to under a larger division, as one may drop the specific name of a new fossil and speak only of the genus to which it belongs. Furthermore, the new names of petrography are in most cases unlike most of those in biology or in mineralogy, in that the things described and given names have no clearly distinguishable characteristics by which they may be recognized. As a result of this inherent vagueness, it is very difficult indeed, from the descriptions published, to obtain a clear conception of what is meant by many of the new petrographical names. Indeed, it may be doubted whether many professional petrographers, to say nothing of those who work in other lines of geology, have a definite conception of the meaning of many of the fifty or more names which have been proposed since 1890.

Principle underlying naming of rocks.—In giving numerous new names to rocks, while no principle is announced by the petrographers, the underlying assumption is the same as that which prevailed in the early days of petrography; that is, rocks may be divided into definite types, which are comparable to definite mineral or animal species. I do not for a moment suppose that petrographers who have introduced these new names would state that they believe this principle. I merely assert that many of the numerous names are justified only if the principle be true.

Responsibility of introducing new names.—The petrographer who introduces a new name for a rock assumes a responsibility which ought to be incurred only after the most careful consideration. Probably some of the new names which have been recently introduced were necessary to the progress of the science. That many of them were not, I venture to believe. One who introduces a new name without the best of reasons for so doing is hindering the advance of the science of petrography, as well as occasioning loss of time and great inconvenience to his fellow workers.

Statement of the problem.—All philosophical petrographers now understand that between all kinds of rocks there are gradations—from basic to acid, from coarsely granitic to glassy, from rich sodium

rocks to rich potassium rocks, from massive lavas to tuffaceous forms, from the freshest rocks to the most altered, from the oldest rocks to the newest, from the igneous to the aqueous rocks; between all of the various forms of the sedimentary rocks. Moreover, many of the important stages of these gradations have been noted. Still further, in one region the gradation from one kind of rock is in one direction, and in another region is in a different direction. For instance, here a granite grades into a diorite; there grades into a syenite.

What shall be the criteria for naming rocks?—These being the facts, the question arises, what is the most important consideration which shall determine whether or not a certain kind of rock shall be assigned a name. It appears to me clear that the most important consideration is *the relative abundance of the rocks.* We must have names for the common things. It is well known that certain of the multifarious kinds of rocks which have been named are more abundant than others. Probably the igneous rocks, which can be included under twenty names, comprise nine tenths or more of the mass of the igneous rocks. It follows that a philosophical method of rock nomenclature involves a knowledge of the relative abundance of the different kinds of rocks.

However, it is not meant to imply that abundance shall be the only consideration in the naming of rocks, but merely that it shall be a fundamental one. While abundance ought to be the first consideration, this idea must not be pushed to an extreme. All rocks which must be assigned names will not be found in equal abundance. Some rocks which do not have specific names assigned to them may be more abundant than some other rocks deserving of a name. For instance, olivine-gabbro may be more abundant than some of the leucite rocks to which names must be assigned. This but illustrates the well-known principle that great variations due to secondary factors shall have weight in proportion to their range, and that therefore they may have an important modifying influence upon the application of the primary considerations.

Influence of rock classification on naming of rocks.—The broad question of rock classification I do not intend here to discuss. However, it is necessary to mention some of the criteria which are recognized in the classification of rocks, since these are also factors in the naming of rocks. By most petrographers, chemical composition, mineral constituents, and rock textures and structures are controlling considerations; but by different petrographers these are placed in different orders of importance. By some petrographers the distinction between plutonic and volcanic rocks is given weight in classification. In making a classification of rocks it is necessary to consider to what extent the altered rocks shall be recognized, and whether such textural terms as porphyry and obsidian shall be used in naming rock species. Doubtless different petrographers would decide these points in various ways.

Now the above factors, which are controlling considerations in the classification of rocks, are of necessity secondary factors in the naming of rocks. If a new rock be found, which, in regard to these secondary factors, is so different from any previously known rocks that it cannot be grouped with any of them by the plan given below, it may be entitled to a new family name, even if not abundant.

But to return to the matter of abundance. After a system of classification shall have been worked out by a petrographer, he must decide what rocks shall have independent names. It is my contention that at this point abundance shall be recognized as having the place of first importance. Names are tools by which we avoid the circumlocutions of descriptions. Since, as already shown, there are everywhere gradations between rocks, not every phase of rock can have an independent name, else the number of names would be infinite. Since every rock phase cannot be assigned a name, what kinds shall be selected for such names? Manifestly those which occur most abundantly. For the common things, the common kinds of rocks, as a matter of convenience, I repeat, we must have names.

As above noted, it has been supposed that a rock might be

designated as a type which has certain characteristics. However, the only method of nomenclature which is logical is that which takes into account the fact of gradation and stages between all rock varieties; that types exist only as descriptions or specimens selected by man, not by nature; but abundance is determined by nature. All this is recognized in the scheme given. The definite forms which are selected for names are those which are abundant. This applies as well to the original forms of rocks as to their altered varieties. Had the varieties of rocks intermediate between those abundant kinds which have been given names been the abundant ones, rather than those to which names have been assigned, these would have been the rocks which should have been given names, and which in all probability *would have been given names* during the first period of the development of the science of petrography.

How shall demands for exactness be met?—But the question now arises as to how the demands of the petrographers for exactness shall be met without introducing a new independent name the moment a slightly different variety of rock is discovered, however small its mass. This demand may be met by the general application of special usages below given. The majority of the abundant kinds of rocks were early assigned names. To less abundant kinds of rocks intermediate between the more abundant kinds, names compounded from the simple names may be used; for example, granodiorite, trachydolerite, trachyandesite.[1] To either the simple or the compound names may be prefixed mineralogical qualifiers, thus further compounding them; for example, quartz-diorite, olivine-gabbro, analcite-basalt, augite-trachydolerite. With these simple or compound names, geographical qualifiers may be used. If the rock is so abundant and definite as to require a specific name, the geographical qualifier may be compounded with the more general name, as Hellefors-diabase. If, however, the idea is exactly to designate the rock occurring at a particular locality, without implying that

[1] Italian petrographical sketches, V, by H S. WASHINGTON: JOUR. GEOL., Vol. V, 1897, pp. 365, 366.

it is so abundant and important as to require a name to enter rock nomenclature, the geographical name may be used simply as a qualifier, as, Duluth olivine-gabbro. This usage gives the most exact discrimination without cumbering nomenclature with a multitude of independent names. In any of the foregoing classes of names the prefixes meta, apo, epi, schisto, gneisso, or other terms may be inserted for the altered rocks.[1]

Under the plan proposed we shall have coördinate simple names of about the value which Rosenbusch has designated as family for rocks which are the most abundant and important. We shall have compound names for rocks intermediate between the more abundant kinds. We shall have names with geological qualifiers, either compounded or not, as the case demands, for a further refinement in discrimination. In any of these three classes of names mineralogical qualifiers may be introduced as an additional discrimination. For all of the previous classes we shall have prefixes, with definite meanings, for the altered equivalents of the different rocks.

The method proposed is practically that of a binomial or trinomial nomenclature. The fundamental names would be based primarily upon abundance, and secondarily upon other factors. The secondary names would be introduced under the same principles.

Application of plan proposed.— How this plan can be worked out may be illustrated by some cases from recently described rocks. (1) *Nordmarkite*,[2] by Washington, is placed as equivalent to *mica-hornblende-quartz-syenite*. The rock is therefore a syenite. Assuming that this rock is sufficiently abundant so that it should have a place in nomenclature, it may be called *nordmarko-syenite*. In the same way, *akerite*[3] (augitic quartz-syenite) may be called

[1] In another place (Metamorphism, Monograph, U. S. Geol. Surv.) I shall discuss in detail the use of these terms. But in the present paper I do not wish to take up the subject. Here I wish merely to suggest a method of handling the altered rocks, rather than to discuss the details of its application.

[2] The petrographic province of Essex county, by H. S. WASHINGTON : JOUR. GEOL., Vol. VI, 1898, p. 799.

[3] JOUR. GEOL., Vol. VI, p. 796.

akero-syenite, if a new name is really necessary and preferable to augitic quartz-syenite. (2) The trachydolerites, designated by Washington as *ciminite*, *vulsinite*, and *toscanite*,[1] may be called *cimino-trachydolerite*, *vulsino-trachydolerite*, and *toscano-trachydolerite*. Under this usage *cimino*, *vulsino*, and *toscano*, take the same place with reference to the trachydolerites, that *hellefors*, *aasby*, *särna*, *ottfjälls* do to the diabases, as used by Rosenbusch (see p. ——). Indeed, Washington himself in one place speaks of *pulaskite* as *pulaskitic syenite*.[2] Following the plan proposed this would be *pulasko-syenite*. (3) As an illustration of the use of mineralogical terms compounded with names already compounded may be given *augite-toscano-trachydolerite*. If desirable, the order of the mineralogical and geographical parts of the name may be reversed. For instance, the leucite-trachytes, which Cross calls *orendite* and *madupite*,[3] may be designated *orendo-leucite-trachyte* and *madupo-leucite-trachyte*.

In all of these cases the geologist knows at once the general character of the rocks referred to. In the first case he knows the rocks are syenites; and, furthermore, that certain varieties of syenites are so abundant and so definite in character as to require a specific designation. In the second case he knows that there is a kind of rock intermediate between the trachytes and dolerites, and, if he knows what trachytes and dolerites are, he has a very clear conception of this rock without any further definition. He further knows that there are variations in the character of the trachydolerites which occur at particular localities, and which, in the opinion of the author, are so abundant and distinctive as to require specific designations. In the third case he further knows at once from the name that certain varieties of the Toscano-trachydolerite contain augite; and infers that this variety is exceptional. He knows that the leucite-trachytes have variations which are thought to be of sufficient importance to require specific designation.

[1] Jour. Geol., Vol. V, pp. 350–361.

[2] Jour. Geol., Vol. VI. p. 804.

[3] Igneous rocks of the Leucite Hills and Pilot Butte, Wyo., by Whitman Cross: Am. Jour. Sci., Vol. IV, 1897, pp. 138, 139.

It is also self-evident that the extreme refinement practiced by Washington and Cross is in no respect lost by using the nomenclature proposed, rather than assigning independent names to particular varieties of rocks described. Indeed, the compound names proposed give additional refinement to that attained by independent names.

In giving the above illustrations I express no opinion as to whether the various syenites, trachydolerites, and leucite-trachytes are so abundant and important as to be worthy of specific names. This is a matter for the petrographer to settle. I merely use these terms as convenient illustrations as to how rock nomenclature can be handled so as to serve the purposes of the general geologist and the specialist, without throwing the subject of petrography into hopeless confusion.

Objection to long names.—The long terms resulting from the plan, as, for instance, augite-toscano-trachydolerite, may be objected to on account of their cumbersomeness and complexity. However, it may be said that these names are simple as compared with many of the names used in organic chemistry, and furthermore that they are justified on precisely the ground that the long names in organic chemistry are justified, that is, they are intelligible names. This is the fundamental point. The present method of naming rocks is not intelligible even to professional petrographers, and an unintelligible method can no longer be tolerated. The method proposed is intelligible to every geologist, whether a specialist in petrography or not, and gives at once the information desired by the general geologist and the extreme refinement demanded by the petrographer. The plan proposed gives all the advantages of generic, specific, and varietal names. If any petrographer can suggest a method of naming rocks which will better satisfy the demand of the petrographer for exactness, and of the geologist for intelligibility, I shall gladly favor such a plan rather than my own proposal.

Why petrographers have not generally followed plan outlined.—The plan suggested is so simple that the question immediately arises as to why petrographers dealing with igneous rocks have

not followed it. Was there not some good reason for the introduction during the past years of many new, independent names? The answer is, petrographers had not worked out any plan as to the naming of rocks, and to assign a new name for each new variety of rock was the easiest way out of the difficulty, although it was disastrous so far as their fellow workers were concerned. Then the honor of giving a new name to rock nomenclature doubtless had a too important effect. Furthermore, many of the petrographers still held, in a subconscious way, to the old notion of rock types, not yet having grasped the idea of general gradation.

Plan followed in case of sedimentary rocks.—That the scheme proposed is practicable is shown by the sedimentary rocks, where it has been substantially followed, although as a matter of necessity rather than a conscious system. In the sedimentary rocks, from the first, gradations were recognized, and hence the tendency to give each variety a new name never got any headway. To illustrate the application of the scheme to the sedimentary rocks, we may take the sandstones. There is an almost infinite variety of sandstones, but it so happens that petrographers have not been directing their energies to the minute discriminations of their variations, and we have not a dozen or score of different names for the different kinds of sandstone. Yet the sandstones of different localities are discriminated and recognized as different from one another by attaching the names of the localities at which the rocks occur to the name, and thus discriminating each rock from all others. For instance, in Wisconsin a peculiar sandstone occurring locally is called the Madison sandstone. From this designation the general geologist at once knows that this formation has the general characters of the rocks which have been called sandstone, and he will not go further. But if he is interested in the Madison district for some reason, scientific, economic, or otherwise, he may go further and learn the peculiarities of the particular sandstone which is found at Madison.

By this method the sedimentary formations are discriminated

the world over. However numerous the names for the sedimentary rocks may be in the future, the method still must be used, for however fine the discriminations resulting from such names, there will be variations from the meanings assigned to these names, and thus the local names are necessary.

In exceptional cases plan followed with igneous rocks.—The simple method proposed of designating the slightly different varieties of igneous rocks from one another, without throwing their nomenclature into hopeless confusion, has already been followed in several cases.

A notable instance is the term *Andendiorite* proposed by Stelzner[1] for a particular rock which has the general characters of a diorite, but which in some respects differs from ordinary diorite, and occurs in the Andes. A geologist who does not care to go into the detailed petrography of the region notes at once that in the Andes is a rock which has the general characters of the diorites, but which in some respects differs from the ordinary kind. He also at once knows that in the Andes is a rock which is different from the ordinary diorites, but which is allied to them. If in his investigative work he wishes to know exactly the meaning of the modifying term, he can do so by reading Stelzner's paper, or by obtaining specimens and an analysis of the rock. In the case of *Andendiorite*, the name has been also used as a new specific name, an dapplied by Iwasaki[2] to a somewhat similar rock in Japan. To a certain degree this shows how the method may be made to work out in practice in reference to the igneous rocks. When here and there other rocks are discovered similar or almost identical with the Andendiorite, and this variety of rock, as a result of these investigations, is found to be so abundant and so definite in its characters as to demand a specific name, the original word *Andendiorite* may be used for this purpose, or, better, a new specific name may be coined for it, and the rock be placed in the scheme of rock nomenclature.

Rosenbusch has used the method of geographical qualifiers

[1] A. STELZNER: Geologie und Paläontologie, von Argentina, p. 213.

[2] Andendiorite in Japan, by C. IWASAKI: JOUR. GEOL., Vol. V, 1897, pp. 821–824.

in a number o finstances precisely as proposed, for discriminating rocks. For example, he describes *helleforsdiabas*, *aasbydiabas*, *sarnadiabas*, *ottfjallsdiabas*.[1] Had some petrographers described these rocks perhaps we would have had four additional, independent names to remember, the value of which we would know absolutely nothing of, without any suggestion whatever as to the family, in Rosenbusch's sense, to which these new rocks belong.

The method proposed has unconsciously been followed to some extent by the United States Geological Survey. That organization has recognized that a sufficient number of independent names could not and should not be coined to designate every variety of rock. It has practically, if not by definition, recognized the endless variation and gradation throughout rock formations, by providing that *aqueous and metamorphic formations alike* should be given local names; for example, Chicopee-shale, Hoosac-schist, Becket-gneiss, etc.[2] This use of local names has furnished a more accurate method of discrimination than could be afforded by independent names. Moreover, only rocks which are present in some quantity have been given formation names. Thus, by practice at least, the idea of abundance as a factor in the naming of rocks has been recognized.

Suggestion to petrographers who have introduced new names.—In this connection it may be suggested that petrographers who have recently introduced new independent names would perform a service to geologists who are not petrographers, and to many other petrographers, by giving in subsequent papers equivalent names on the basis of the plan above advocated, to the special rocks to which they have given names. If this be done, the relative merits of the two plans will be tested. Within a short time it will be seen whether geologists and petrographers use the independent names or the more general names compounded with geographical and mineralogical terms. Where a new independent name was really needed, and performs a service in the

[1] Mikroskopische physiographie, II, Massige Gesteine, H. ROSENBUSCH; S. 219–220.

[2] Holyoke folio No. 50, Geological Atlas of the United States.

advancement of science, it will be sure to be retained. If it drops out of use, its proposal was premature.

Summary of advantages of proposal.—In conclusion, some of the advantages of the foregoing plan may be summarized:

1. The plan proposed serves all the purposes of nomenclature, from names of a general character to those giving the most minute discriminations. It has the advantage of grouping different varieties of rocks under terms, the general meaning of which is known to all. In the matter of nice discrimination it far surpasses the plan of independent new names for new varieties of rocks. It permits at once any difference in the character of a rock, however slight, to be discriminated, and it permits the growth of petrography by the grouping of the allied varieties together under a new specific name so soon as they shall have been found so abundant, so peculiar, or so important as to demand such a name. The professional petrographer will thus have a much more convenient and elastic nomenclature for describing rocks than he has at present. He may ignore minor differences between rocks in one sentence, and in the next sentence deal with the most refined differences between them. Thus the plan advocated meets both the demands of the geologist and of the specialist in petrography.

2. The plan proposed puts the available information of petrography in such shape that some master mind in the future may reduce the subject to a science. The present scheme of rock nomenclature makes it impossible for any person to get the facts clearly before his mind in such a way that they can be handled. The provisional scheme proposed accomplishes this end. If it be generally followed by petrographers, it is probable that within a few years it will be possible to propose a definite scheme of rock nomenclature, the terms of which correspond roughly to genus, species, and variety in biology.

3. It is believed, if once rock nomenclature be placed upon a reasonable basis, that this will be a great step toward the establishment of a satisfactory scheme of rock classification.

4. Under the plan suggested it will be easy for the student

to get definite notions of the common kinds of rocks. Having this knowledge, he knows without explanation the meaning which is to be attached to a name compounded of two of them. He knows without a moment's reflection the meaning of a mineralogical qualifier prefixed to a noun. He knows that a geographical qualifier means the particular variety of rock which occurs in a certain district. Thus it will be possible for a student to gain a comprehensive knowledge of the chief kinds of rocks at a very early stage of work, and to supplement his general knowledge by details as his work advances.

5. A further advantage of the foregoing plan will be that many of the earliest rock names proposed will be retained, although some may be abandoned. The reason why so many of the old names will be retained under the plan proposed is that many of the abundant rocks were first found; for, as already noted, while the petrographers supposed they were following the plan of naming rocks on the basis of types, they were largely following the plan of naming rocks on the basis of abundance.

6. Still another of the manifest advantages of the plan is that it throws the emphasis on the proper thing; it calls attention to the common, not to the exceptional, rocks. Many petrographers, in discussing the rocks of an area, describe with the utmost particularity the minute characteristics which are peculiar to the exceptional rocks of the district or region, and say comparatively little of the common rocks which compose the great mass of the rocks of the area. Of course, there is some justification for this, in that the characters of the common forms are known. But all papers describing the geology of a region should be so framed as to give a clear conception of the common kinds of rocks which are preponderant, and indicate that the exceptional things described in such detail are only so described because of their peculiarities. To the reader in some way should be conveyed the idea of the relative abundance of the rocks. The error of emphasizing the exceptional and overlooking the common phenomena has been one of the most pernicious mistakes which runs throughout geological papers and text-books. For instance,

many pages in a text-book are given to a discussion of earthquakes, and only a small fraction of that space is given to the vastly more significant, slow earth movements which occur without earthquakes or with earthquakes as secondary phenomena.

7. Finally, the foregoing plan has one further advantage. It emphasizes a great law of nature, the law of gradation—the principle that ultimately there is no such thing as an absolute type. In this respect, petrography, if it will but use its opportunity, has an advantage over any other subject. In biology there have once been gradations between species, between families, between classes. Many of these gradations have been destroyed in the course of evolutionary processes. However, in petrography all of the gradations yet persist, and thus it furnishes the best illustration of the principle of gradation, a fundamental principle of nature.

C. R. Van Hise.

Madison, Wis.,
November 1899.

Editorial

A proposed International Journal of Petrology.—The committee appointed by the Seventh International Congress of Geologists to consider plans for the establishment of an International Journal of Petrology has chosen Professor F. Becke of Vienna, well known as the editor of *Tschermak's Mittheilungen*, President of the Committee, and has taken the first steps toward the organization of such a journal. It has been proposed that articles appearing in it shall be printed in French, German, or English at the option of the author.

While primarily intended for the publication of reviews and abstracts of all petrographical papers wherever published, it is suggested that it may include also articles which shall appear in it for the first time. The carrying out of this must depend upon the financial support the journal receives.

The journal is to be managed by a committee appointed by the International Congress of Geologists, the committee to select an editor who shall have two assistants ; the editor and assistants to receive salaries for their services.

The desirability of having one source, thoroughly up to date, to which to turn for information concerning all matters published on petrology is self-evident to all attempting to keep abreast with the rapid advance of this science. One has only to observe what a great impulse to the science of mineralogy has been given by the establishment of Groth's *Zeitschrift fiir Krystallographie*, to be convinced of the usefulness and convenience of such a journal.

The necessity of forecasting as correctly as possible the financial support obtainable for such a journal has suggested to the American members of the committee the plan of calling attention to the enterprise and of inviting all interested in its success to communicate to either of them such suggestions or information as may aid in estimating the amount of annual

subscriptions or contributions that may be obtained from this country.

It is expected that the chief support will come from individual subscriptions and from university and public libraries, but it may be possible to obtain assistance, in the first years of the undertaking at least, from other sources.

J. P. Iddings,
L. V. Pirsson,
Members of the Committee for America.

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Do State Surveys Pay? The question has often been asked, and in the coming legislative season probably will be asked many times. An answer is usually desired which deals with dollars and cents, but, perhaps, a partial answer may be given by noting the sort of requests for miscellaneous information which consume a not unimportant portion of the time of survey officers.

For illustration, the requests of a single day in the office of one of the smaller surveys may be noted. Two came in the morning mail. The first was from a professor in one of the smaller colleges, asking for twenty copies of a certain pamphlet to use in the class room. The second was from a consulting chemist, retained by some eastern capitalist to investigate the advisability of establishing an important manufacturing plant in the state. He wished to know the amount, quality, and average cost of certain ores which were being mined there, and the probability of larger quantities being mined. A third request was made in person, by the engineer in charge of locating an important line of railway. He wished a report upon the mineral resources of all kinds along the proposed line. A fourth request came in the afternoon mail. It was from a high-school teacher, who wished for a certain report to use in teaching. The last request was from a reporter, sent to secure an interview relative to certain reputed iron deposits that the local papers of a certain section of the state were making much of. The city editor of a big daily wished to know whether there was any iron there. If so, how much. What was its quality, and what the chances of securing its development if proper publicity were given the matter. He wanted "facts which could be relied on," and so he sent to the survey.

All these requests were attended to in detail, and the tired official wondered when he was to get time to write, revise, and print the report on the year's field work.

H. F. B.

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE.[1]

DAVIS,[2] in connection with an account of the Triassic formation of Connecticut, maps the boundary between the Triassic and crystalline rocks to the east and west. The prevailing monoclinal faulted structure in the Triassic involves a similar structure in the crystallines below, and it is believed that the structure observed in the Triassic is due to the slipping of large slabs of the crystalline rocks and the overlying Triassic rocks, in such way that each slab was elevated with reference to the slab next to the west, or, lowered with reference to the one next to the east. The explanation of the cause of the faulted structure is the same as that offered in a previous paper.[3]

Merrill[4] gives a general account of the geology of the crystalline rocks of southeastern New York.

The crystalline rocks lie on the east of the Hudson River, in New York, Westchester, Putnam, and Dutchess counties, whence they extend into Connecticut; and on the west of the river, in Orange and Rockland counties, whence they extend southwesterly into New Jersey. The lowest member is a coarse hornblende-granite which forms the central mass of the range of mountains known as the Highlands of the Hudson, and, in their highest peak, Breakneck Mountain, is exposed through a vertical height of nearly 1200 feet. Other granites, nearly free from hornblende, occur in subordinate masses. The granites are probably igneous and of great age. On their flanks are banded gneisses, the Fordham Gneiss, consisting chiefly of quartz and orthoclase, with biotite and hornblende, and containing numerous beds of magnetic iron-ore. The gneisses on the south side of the Highlands extend through Westchester county in a series of folds with southwesterly trend, and on the northern slope of the Highlands, at several

[1] Continued from p. 425, Vol. VII, JOUR. GEOL.

[2] The Triassic formation of Connecticut, by WM. M. DAVIS: Eighteenth Ann. Rept. U. S. Geol. Surv., Part II, 1898, pp. 1–192. With geological map.

[3] The Structure of the Triassic Formation of the Connecticut Valley, by WM. MORRIS DAVIS: Seventh Ann. Rept. U. S. Geol. Survey, 1888.

[4] The geology of the crystalline rocks of southeastern New York, by F. J. H. MERRILL: Report of the New York State Museum, 1896, pp. 21–44.

places in Dutchess county, are overlain unconformably by quartzites, which are believed to be of Cambrian age.

Ries[1] describes the geology of Orange county, New York. Pre-Cambrian rocks form the Highland region in the eastern part of the county, the northwestern side of Bellvale Mountain, and a series of rounded knob-like hills extending from Sugar Loaf village to Newburgh. They comprise gneiss, at times massive and resembling granite and limestone. The crystalline rocks are folded and faulted, the folds plunging frequently to the northeast.

In the south-central part of the county is found an area of white and blue limestone, which continues south into New Jersey. The white limestone is found in New Jersey to contain fossils of Cambrian age. Exposures are found east of the road, 1¼ miles west-southwest of Pine Island station, which show the passage of the blue into the white limestone. Other, similar areas of limestone are found to the northeast.

Limestones interbedded with the gneisses are found at Popolopen Pond, and again at Fort Montgomery.

Wolff and Brooks[2] present a final discussion of the age of the Franklin white limestone, of Sussex County, N. J. The pre-Cambrian age of the white limestone is believed to be shown by the following facts:

The supposed cases of interbedding of the white limestone and the Cambrian quartzite are found to be due to faulting, or to peculiar conditions of deposition. On the other hand, while it is difficult to prove that the white limestone and pre-Cambrian gneiss are actually interbedded, narrow bands of the true gneiss do occur within the white limestone belt, and seem to be an integral part of the series.

The granite occurring in the area is intrusive in the white limestone, and the nature of the contacts of the granite and the Cambrian quartzite indicates that the intrusion was prior to the deposition of the Cambrian quartzite and blue limestone. While the intrusion of the granite has caused local metamorphism of the white limestone, it is believed that the crystallization of the limestone antedated the granitic intrusion, and was contemporaneous with the crystallization of the gneisses in their present form.

[1] Geology of Orange county, by HEINRICH RIES: Forty-ninth Ann. Rept. of N. Y. State Museum, for 1895, Vol. II, 1898, pp. 395–475. With geological map.

[2] The age of the Franklin White limestone of Sussex County, N. J., by J. E. WOLFF and A. H. BROOKS: Eighteenth Ann. Rept. U. S. Geol. Surv., Part II, 1898, pp. 425–457. With geological map.

The structural relations of the three belts of Cambrian blue limestone with the gneiss and white limestone are such as to indicate unconformity. Along the normal contacts of the blue and white limestone the quartzite intervenes between the two. The bedding of the blue limestone and underlying quartzite is everywhere conformable, while the dip of the foliation of the white limestone and the gneisses is discordant with this bedding.

Isolated patches of Cambrian quartzite are found within the white limestone area. In one place a crevice in the white limestone is filled with the Cambrian quartzite containing undoubted pebbles of the white limestone.

Comment.—The results above presented bear evidence of close and careful field study. The pre-Cambrian age of the white limestone is clearly proven, thus satisfactorily disposing of a much disputed question.

There now remains the question of the origin of the gneisses. In this connection attention may again be called to the marked similarity of the limestones and associated gneisses of the New Jersey area, to the pre-Cambrian limestones and associated gneisses of the Adirondack and Original Laurentian districts to the north. In a general way it would seem that the story worked out for one of the districts may perhaps apply to the others.

Weidman[1] describes the pre-Cambrian igneous rocks of the Utley, Berlin, and Waushara areas, in the Fox River Valley of Wisconsin. They range from volcanic flows to masses of deep-seated origin, with corresponding textures. The rock of the Utley area is a metarhyolite, at Berlin a rhyolite-gneiss, and in the Waushara area a granite. Analyses of the rocks of the three areas show a close similarity in chemical composition, and it is believed that the rocks represent phases of a single parent magma. The rocks have been metamorphosed to different degrees, and the results of the metamorphism, particularly of the feldspars, are described in detail.

The crystalline rocks are unconformably overlain by flat-lying Potsdam and Ordovician sediments. From their similarity in composition to the Baraboo volcanics, which are considered to be of Keweenawan age, it is believed that they belong to the same province, and are therefore of Keweenawan age.

[1] A contribution to the geology of the pre-Cambrian rocks of the Fox River Valley, Wis., by SAMUEL WEIDMAN: Bull. Wis. Geol. & Nat. Hist. Surv., No. III, 1898, pp. 63.

Norton,[1] in a description of the artesian wells of Iowa, discusses the attitude of the Algonkian floor. In the northwestern part of the state the Algonkian outcrops as the Sioux quartzite. From here it sinks rapidly to the south and east, and is discovered near the area of its outcrop only by the steep wells at Sioux City, Hull, and Le Mars. In the east-central part of Iowa is a slight elevation of the Algonkian floor, disclosed by the artesian well at Cedar Rapids. In Wisconsin the Algonkian outcrops as the Baraboo quartzite, a rock similar to the Sioux quartzite. From this outcrop the Algonkian sinks gently to the southwest, as it is reached by the drill at Lansing, Iowa. At no other place in Iowa has the drill gone deep enough to reach the crystalline rocks.

Comment.—The connection of the crystallines reached by the drill with the Algonkian outcrops of Iowa and Wisconsin is conjectural, and perhaps it would be better not to assume that such crystallines are all Algonkian. However, the observations are of interest as showing the attitude of the ancient crystalline floor, whether Archean or Algonkian.

Beyer[2] maps and describes the part of the Sioux quartzite formation exposed northeast of Sioux Falls in sections 10, 11, 14, 15, 22, and 23, T. 102 N., R. 48 W., South Dakota. The quartzite dips from 3° to 7° to the southwest. An accurate estimate of the thickness may not be given, but 1500 feet is a liberal one.

Slate is exposed in the area in isolated outcrops, but never in contact with the quartzite. In composition it corresponds very closely to the quartz-slate of Irving and Van Hise.[3] Intruding the slate are diabase dikes, which have followed the bedding.

The relations of the slates and quartzites cannot here be ascertained. However, from the relations of the two outside of the area it is believed that the slates are the upward continuation of the quartzite, and that they have been removed in large part.

The age of the Sioux quartzite is believed to be pre-Cretaceous. Its reference to the Huronian may be supported by the following facts: The lithological characters of the quartzite are identical with those of

[1] Artesian wells of Iowa, by W. H. NORTON: Geol. Survey of Iowa, Vol. VI, 1897 (The Algokian, pp. 139–140).

[2] The Sioux quartzite, and certain associated rocks, by S. W. BEYER: Iowa Geol. Survey, Vol. VI, 1897, pp. 69–112.

[3] The Penokee iron-bearing series, by R. D. IRVING and C. R. VAN HISE: Tenth Annual Rept. U. S. Geol. Survey, 1890, p. 370 et seq.

the Baraboo quartzite in Wisconsin, which has been referred by Irving and Van Hise to the Huronian. The diabase intruding the slate, supposed to be the upward continuation of the quartzite, is strikingly similar to intrusives which are peculiar to the Huronian in the Lake Superior region.

Frazer[1] sketches the geology of an area in the vicinity of Galena, in the Northern Black Hills of South Dakota. Mica-schists, thought to be upper members of the Archean, are found striking northeast-southwest, and dipping at angles from 38° to 85°. They are generally micaceous and coarse-grained, but vary greatly, sometimes passing into nacrite- or hydromica-schist, and sometimes, though more rarely, assuming a heavily bedded character reminding one of gneiss.

Todd[2] reports on a section across the Black Hills from Rapid City westward. The alternating slate and quartzite beds of the Algonkian were found to be folded in a most intricate fashion. A number of the folds were worked out. In most cases the lamination and stratification seem to correspond in direction.

Comment.—The last observation differs from one made by Van Hise, who, as a result of work done in 1890, concluded that the prominent foliation of the Black Hills is independent of the bedding, and as a rule cuts across it.

Griswold[3] describes the geology of Helena, Montana, and vicinity.

Middle Cambrian, or Flathead, quartzite forms an important part of the ridge stretching from Helena southeast to Montana City, and northwest, west, and south around Mount Helena. The sedimentary rocks underlying most of the area of the city, on the north side of this Cambrian quartzite, are classed as Algonkian. The Algonkian rocks vary from clay-slates to micaceous, sandy, or calcareous slates, which often become quartzites or limestones. The Algonkian slates seem to conform to the overlying strata in the dip of their beds. As there are many small folds, it is difficult to determine the thickness; 5000 feet does not seem too large a total.

Gilbert[4] maps and describes the geology of the Pueblo quadrangle,

[1] Notes on the Northern Black Hills of South Dakota, by PERSIFOR FRAZER: Trans. Am. Inst. Min. Engineers, Vol. XXVII, 1898, pp. 204–228.

[2] Section along Rapid Greek from Rapid City westward, by J. E. TODD: South Dakota Geol. Survey, Bull. No. 2, 1898, pp. 27–40.

[3] The geology of Helena, Montana, and vicinity, by L. S. GRISWOLD: Journal of the Association of Engineering Societies, Vol. XX, 1898, pp. 1–18.

[4] Geol. Atlas of the U. S., Pueblo folio, No. 36, by G. K. GILBERT: U. S. Geol. Survey, Washington, 1897.

including part of Pueblo county and the southeast corner of Fremont county, Colorado. Archean rocks occupy two small tracts in the southwestern part of the quadrangle. The more abundant kinds of Archean rocks are mica-schist, mica-gneiss, and granite. The schists and gneisses strike north to northwest, and are nearly vertical. Their origin is not known. The granite is intrusive in the schists and gneisses.

The Archean rocks are overlain unconformably by Paleozoic and Mesozoic sediments.

Lakes[1] sketches the geology of the Gunnison gold belt in Gunnison county, Col., from the Cebolla River on the west to the head of Taylor Park and the Sawatch range on the east. The northern part of area is included in the granitic system of the Sawatch range. The southern part is occupied by schists and gneisses, underlain by coarse massive granite. The schists and gneisses are of pre-Cambrian age, but whether Algonkian or older has not been determined. The contact of the schists and gneisses with the underlying granite is an eruptive one, the granite containing fragments of the schist, giving the impression that the schists had been floated up on an underlying molten or semi-molten sea of granite. Cutting the schists are occasional dikes of diabase and possibly basalt and andesite, and resting on the eroded edges of the schists are various later overflows of andesitic breccia, rhyolite, trachyte, and basalt.

Aguilera[2] gives a synopsis of the geology of Mexico. The most ancient, or Azoic, rocks are granites, gneisses, and schists, presenting many variations. They extend lengthwise along the Pacific coast, forming a narrow band, interrupted in places, and sending ramifications toward the central part of the country, in some places almost to the eastern coast. They occupy the southern part of the state of Puebla, a part of the Sierra Madre Mountains in Chiapas, and extensive portions of Oaxaca and Guerrero; they are found also in Zacatecas, around Fresnilo; in Guanajuato, in the vicinity of the capital; in Sinaloa, around the crests of the Sierra Madre; in Sonora, in its northwestern and western parts; in lower California, where

[1] Sketch of a portion of the Gunnison gold belt, including the Vulcan and Mammoth Chimney mines, by ARTHUR LAKES: Trans. Am. Inst. Min. Engineers, Vol. XXVI, 1897, pp. 440–448.

[2] Sinopsis de Geologia Mexicana, by JOSE C. AGUILERA: Bol. del Inst. Geol. de México, Nums. 4, 5, & 6, 1897, Part II, pp. 189–250. With geol. maps.

they constitute the central Cordilleran axis of the peninsula; in Vera Cruz, in its western region, limited by Puebla, in the canton of Zongolica.

In the southern part of Puebla, and in Guerrero and Oaxaca, where the greater part of the exposures occur, the sequence is as follows, from the base up: (*a*) Porphyritic gneiss, similar to augen-gneiss, at the base losing its lamination and passing into a kind of granite. (*b*) Phyllite-gneiss, resting upon, and grading below into preceding beds. (*c*) Very abundant mica-schist, in some places garnetiferous, and in perfect conformity with the phyllite-gneisses. (*d*) Phyllites, very argillaceous in the upper part, and showing gradual diminution in the proportion of clay toward the base. In accordance with this change of composition, the structure varies from perfectly schistose to laminated, and finally to stratiform.

After the deposition of the argillaceous phyllites, and before the termination of the Paleozoic, there have occurred numerous eruptions, in order of age as follows: Granite-gneiss, granite, granulite, hornblende granite, pegmatite, greisen, and diorite.

Comment.—The ancient rocks are mapped as Azoic, and in the text are described as Archean and Primitive, so that these three terms are used in the same sense, to cover all rocks below the Paleozoic. The pre-Paleozoic rocks are both sedimentary and igneous, and not improbably may represent the Algonkian as well as the Basement Complex.

C. K. LEITH.

MADISON, WIS.

Reviews

Geology of the Yellowstone National Park. Part II. Descriptive Geology, Petrography, and Paleontology. By Arnold Hague, J. P. Iddings, W. H. Weed, C. D. Walcott, G. H. Girty, T. W. Stanton, and F. H. Knowlton. Washington: Government Printing Office, 1899. Pp. xviii + 893, 121 plates and 4 figures. Monograph XXXII of the United States Geological Survey.

This compendious monograph is about equally divided between petrography and paleontology, having about 440 pages of text in each division, and of the 121 plates 62 are given to fossils, and 59 and the four figures to petrography and geology. Of the fourteen chapters Iddings furnished seven on the petrography, Iddings and Weed two on the geology, Weed and Hague each one on the geology. Walcott's work on the Cambrian fossils and Girty's on the Devonian and Carboniferous go into one chapter. Stanton furnishes one on the Mesozoic fossils and Knowlton one on paleobotany.

The first chapter, by Iddings and Weed, is on the descriptive geology of the Gallatin Mountains, which mountains extend eighteen miles within the boundary of the park. The diversity of the geological features in this area is remarkable. The sedimentary rocks begin with the Cambrian and range through the Silurian, Devonian, Carboniferous, and Juratrias into the Laramie division of the Upper Cretaceous. Cutting through the sedimentary series are intrusions of igneous masses in the form of laccoliths, sheets, and dikes. The sedimentary rocks are slightly folded and strongly faulted. Extensive erosion has exposed large areas of the rocks in their structural relations. To still add to the diversity, the surface has been glaciated.

The second chapter describes the intrusive rocks of the Gallatin Mountains. These consist mainly of fine-grained, aphanitic masses, mostly porphyritic and andesitic in character. The Indian Creek laccolith is hornblende-mica-andesite-porphyry. The Bighorn Pass sheet

consists of kersantite of complex composition; the Gray Mountain mass and connected sheets consist of andesite and andesite-porphyries. The Mount Holmes bysmalith, Gallatin River laccolith, and the Bunsen Peak mass are composed of dacite-porphyry.

Chapter three deals with Electric Peak and Sepulchre Mountain, which are described as parts of a Tertiary volcano faulted across the neck with a vertical throw of more than 5000 feet. The deeper parts of the volcano consist of sedimentary strata cut by dikes, sheets, and the stock or conduit of the volcano. The ejected breccia and lava flows, along with the upper portion of the conduit, make up Sepulchre Mountain. The andesitic lavas of Sepulchre Mountain change to diorites and porphyries in Electric Peak. Rocks with the same chemical composition in one place crystallize into diorites and in another place form andesites. Both types are illustrated by photomicrographs and photographs. Maps and section illustrate fully the relations of the different rocks.

The northern end of the Teton range, which occurs in the southern part of the park, is described at length in the next chapter. This range is made up of a nucleus of crystalline schists and gneisses, which are overlain by flexed and faulted Paleozoic and Mesozoic strata. The eroded edges of these old sedimentary rocks were covered with volcanic basic breccias and after another period of erosion an extensive outflow of acidic lava covered the whole area and still conceals the northern extremity of the Teton Mountain.

Mr. Hague, in chapter five, describes the irregular diversified mountainous area known as Huckleberry Mountain and Big Game Ridge. It lies in the southern part of the park and in the Forest reservation and consists of a number of northwest-southeast ridges, composed mostly of Mesozoic rocks. The Cretaceous sandstones are the prevailing rocks, but small areas of older strata are exposed. The rhyolites of the park plateau abut against the slopes of the upturned edges. Besides Huckleberry Mountain and Big Game Ridge, there are other elevations known as Wildcat Peak, Bobcat Ridge, Chicken Ridge, and Two Ocean Plateau. The principal igneous rocks in the area are dacites, surrounded by apparently younger rhyolite. In the gorge of the Snake River the Madison limestones, Teton sandstones, Ellis limestones, and shales are exposed. The Snake River hot springs occur near the contact of the rhyolite with the limestones. The travertine deposits around the springs resemble those around the Mammoth Hot Springs

and the lime is derived from the Madison limestone. The Laramie strata are exposed near the base of Pinyon Peak, as shown by the characteristic Wolverine flora. The conglomerate of Pinyon Peak is probably Eocene, as it underlies the basic breccias of the Absaroka range and overlies unconformably the Laramie sandstones. Outlet Canyon, the picturesque gorge cut through Chicken Ridge, at one time served as an outlet into Snake River for the waters of Yellowstone Lake. The Yellowstone Canyon now furnishes an outlet for these waters into the Atlantic, instead of into the Pacific. Two Ocean Plateau, which rises 10,000 feet above the sea level, forms a part of the Absaroka Range. It is made up of volcanic breccias and tuffs.

Chapter six describes the southern end of the Snowy range, which forms the northeast corner of the park. It consists of a broad core of crystalline rocks, bordered by Paleozoic rocks, which dip away from the crystalline axis. Detailed sections of the Paleozoic sedimentary rocks are given, but the igneous rocks are described in other chapters.

Chapter seven is especially interesting to petrologists, as it describes in detail the structural features and petrographic characteristics of a dissected volcano in the Crandall Creek basin. It lies on the border of the park forest reservation and east of the park proper. The great value to petrology lies in the clear delineation of the inside of a volcano, and in giving additional field evidence of the gradation of coarsely crystalline so-called Plutonic rocks into the glassy eruptives. "The coarsely crystalline gabbros and diorites, with smaller bodies of granite, exposed for a height of 3000 feet, are plainly seen to have been intruded into a vast accumulation of basaltic tuff and scoriaceous breccia. From this coarsely crystalline mass as a center, dikes of fine-grained rock penetrate the surrounding lavas in all directions, the dike rocks becoming fine-grained rapidly as they leave the once heated core. They form a network of branches which connect the outlying aphanitic and characteristically volcanic rocks with the more crystalline dikes near the core which finally merge into the granular body of the gabbro and dorite." The whole forms one complex network so closely interwoven that the gabbros of the core are as truly volcanic as the glasses on the surface. The volcano has built itself upon a ridge of eroded Paleozoic rocks, and beneath the volcano are remnants of Eocene breccias and lava flows.

The next chapter treats of the Absaroka range which consists mainly of volcanic breccias with smaller quantities of massive flows. It contains

an account of their field occurrence and distribution, and a systematic description of their mineralogical composition and characteristics. The oldest rocks occur at the north end and consist of acid breccias found in remnants underlying early basic breccias. The former consist mainly of hornblende-andesite and hornblende-mica-andesite. The basic breccias consist of pyroxene-andesite, passing upward into basalt. Upon these were thrown other acid breccias, similar in composition and appearance to the earlier ones. These grade upwards into later basic breccia, consisting of andesites with less basalt than occurs with the earlier flows. This last basic breccia forms the southern portion of the range within the park and also the Two Ocean Plateau. Remnants of surface flows of massive andesite form the summits of Mt. Stevenson, Mt. Doane, Colter Peak, and several prominent mountains south of Sylvan Pass.

Chapters nine, ten, and eleven discuss different classes of the volcanic rocks. The Absarokite-Shoshonite-Banakite series consists of certain basaltic and other rocks associated with andesitic breccias and basalt flows which have considerable orthoclase and a comparatively high percentage of potash. They occur as lava flows and dikes in various localities. They have been classified according to their chemical and mineral composition.

The rhyolites in the park are almost wholly extrusive lavas of uniform chemical composition, but differing widely in color, texture, and megascopic habit. The mode of occurrence, and the microscopic features of phenocrysts, spherulites, lithophysae, are described in detail, and beautifully illustrated. The modifications of crystallization, lamination and the formation of pumice are referred to heterogeneity of the molten magma, especially with reference to the amount of vapors contained in it. In some places basalt appears to have been inclosed and partly fused by the rhyolite.

The recent basalts are distinguished from the early brecciated ones by being ophitic and non-porphyritic. They overlie the rhyolite in most cases, but in some places they occur beneath it, and in some places between the older and younger sheets of rhyolite.

With chapter twelve begins the paleontologic part of the work. The Director of the survey describes the Cambrian fauna from which twenty-one species have been obtained. Several of these are new, and are here described and illustrated for the first time. No fossils of undoubted Silurian age have been obtained. The Devonian is

represented in the Three Forks limestone. A varied but wholly Lower Carboniferous fauna has been obtained from the Madison limestone.

In chapter thirteen Mr. Stanton describes the Mesozoic fossils. These were obtained from the Gallatin range, near Electric Peak, Teton range, in the vicinity of Wildcat Peak and Huckleberry Mountain, and from the Cretaceous ridges in the southern end of the park and Yellowstone Forest Reserve. There are seventy-eight invertebrates, one of which is supposed to be of Triassic age, forty-six are Jurassic, and thirty-two are Cretaceous. The fossils are mainly from the Ellis division of the Jurassic and the Colorado of the Cretaceous.

The last chapter, by Mr. Knowlton, on the fossil flora, is a long one, covering 233 pages, besides 45 plates of illustrations. The Mesozoic flora is confined to the Laramie sandstones of the Cretaceous, and is found on Mt. Everts, near Mammoth Hot Springs, and at the base of Pinyon Peak, near the head of Wolverine Creek. The Tertiary flora is quite varied, and full of biological interest. On comparing it with the present it signifies great climatic changes since the Miocene. It is found in numerous localities associated with the breccias and silts of the igneous rocks, where the muds and silts furnished a soil favorable to plant growth. The Tertiary fossil flora embraces about 150 forms in thirty-three orders. The interesting fossil forest trees of Specimen Ridge are illustrated with photographs of the trees in the field and enlarged microscopic sections showing the cellular structure.

The petrographical and paleontological features of the Yellowstone National Park are certainly described in great detail, and the monograph will no doubt prove to be a valuable handbook to scientists, especially to those visiting the region.

T. C. H.

Report on the Geology and Natural Resources of the Area included by the Nipissing and Temiscaming Map Sheets, comprising portions of the district of Nipissing, Ontario, and of the county of Pontiac, Quebec. By ALFRED ERNEST BARLOW. Geological Survey of Canada. Part I, Annual Report. Vol X, 1899, pp. 302.

This report, accompanied by two well-executed maps on a scale of four miles to the inch, and covering an area 6912 square miles of the northern Protaxis of the Dominion of Canada, is a valuable addition to the literature of the pre-Cambrian of North America and is a further

installment of the work which is being systematically carried forward by the Dominion Geological Survey on these older rocks. The two maps, constituting what are known as sheets Nos. 131 and 138 of the Canadian Series, lie in the Upper Ottawa district along the border of the two Provinces of Quebec and Ontario, and comprise portions of both. Lake Nipissing and Lakes Temagami, Temiscaming, and Keepawa, as well as many smaller bodies of water, are included in the area, and afford along their shores especially good opportunities for the prosecution of geological work.

After presenting a general account of the early explorations in this region, some of which date back almost to the time of the earliest settlement of the country by the French, and of previous surveys, the physical features of the country are described. The area is a great uneven, or gently undulating, rocky plateau, sloping somewhat to the east and southeast, having a general elevation of 900 to 1200 feet above sea level, the level being so nearly uniform that hills 50 to 100 feet higher are conspicuous topographical features. This peneplain is traversed in a north and south direction along one line by a very deep and narrow rocky gorge, in which lie Lake Temiscaming and the Ottawa River. The hills, or cliffs, rise to a height of 400 to 600 feet from the water on either side, while the water of the lake is 400 feet deep; the bottom of the gorge being filled with a fine silt. The depression is thus at least 1000 feet deep and represents a great canyon similar to those which are found on the margin of the northern Protaxis at so many other points. Several smaller rivers also occupy similar depressions. "The detailed examination of the region, however, amply demonstrates that the sculpturing to which the surface owes its present configuration was practically completed long before the advent of the glacial epoch, and that the main valleys, especially those of the Ottawa and Mattawa rivers, were in existence long prior to the deposition of the Palaeozoic sediments." With the exception of some comparatively small areas occupied by Palaeozoic outliers, ranging in age from Black River to Niagara, the district is underlain by rocks of Laurentian and Huronian age. The Laurentian, with the exception of a few small occurrences, is represented exclusively by the fundamental gneiss, a mass of granitic and dioritic rocks, usually possessing a foliated structure in which are many streaks, bands, or inclusions of basic character, allied to diorites or diabases in composition, and representing either basic segregations from the granitic magma or portions of

basic intrusions caught up in it. This fundamental gneiss, it is believed, probably represents the original crust of the earth which has undergone successive fusions and re-cementations before reaching its present condition. In placing these rocks at the base of the series it is not intended to assert that they stand for any distinct or prolonged period of geological time, nor to affirm that these rocks, in their present condition and with the foliation which they now possess, antedate those of the Huronian system. This, as is shown, is not the case in many, or even probably in most, instances.

The chemical and mineralogical composition of the gneisses, as well as the character and origin of their foliation and the genetic relation of their associated pegmatites, are considered at length, and many interesting facts brought forward which cannot here be further discussed.

The Grenville series, so extensively developed further south, is in this northern area represented only by a few very small and unimportant occurrences of highly crystalline limestone and a single occurrence of gneiss. They occur isolated from one another and surrounded by fundamental gneiss on every side, and are referred to the Grenville series on account of their identity in petrographical character with the areas of this formation immediately to the south.

The district also includes large tracts of country underlain by pyroclastic and epiclastic rocks, forming a northeasterly extension of the development of the "typical" Huronian area on the north shore of Lake Huron. At one place on Lake Temiscaming, these Huronian rocks are found resting upon the floor of fundamental gneiss on which they were originally deposited, and of whose detritus they are made up, everywhere else the fundamental gneiss has been refused or softened and penetrates the superincumbent Huronian. The total thickness of the Huronian in the area is about 1800 feet, made up as follows: 1. Breccia-Conglomerate, 600 feet. 2. Shales and slaty greywackes, 100 feet. 3. Quartzose grit or Arkose, 1100 feet. Associated with these Huronian sediments are numerous intrusions of gabbro and diabase, some of which pass over gradually into flesh-red granites, representing, it is believed, portions of one and the same magma.

No attempt is made in this report to correlate the Grenville series and the Huronian of the area, as the facts are insufficient to warrant the attempt. And it may be remarked incidentally in this connection that a statement, made on page 415 of the current volume of this

JOURNAL, in reviewing some other recent papers on the Canadian pre-Cambrian, is scarcely correct. The statement is as follows:

"The succession and correlation proposed in the above papers by Adams and Barlow and by Ells are fundamentally different from the traditional one which has been held in Canada for many years. The first departure is in placing the Grenville and Hastings series as equivalent to the Huronian."

In the papers in question this correlation was not definitely made, but it was stated in reference to the Hastings series that "both lithologically and stratigraphically the rocks bear a striking resemblance to rocks mapped as Huronian in the region to the north and north-east of Lake Huron, and it seems very likely that the identity of the two series may eventually be established. The two areas, however, are rather widely separated geographically, and the greatest care will have to be exercised in attempting such a correlation."[1]

The further statement made by the reviewer that "Ells places with the Huronian all the sedimentary rocks of Eastern Canada" is also manifestly inaccurate, seeing that while it might terminate the controversy concerning the upward extension of the Huronian to include in that system the whole Palaeozoic succession, Ells cercainly did not advocate this course.

The Palaeozoic outliers in this area and especially that of Niagara age are of exceptional interest. Geographically this outlying patch of Niagara is so widely separated from any other locality where rocks of this age are now known to exist, that it has been a question as to whether it was formerly connected with the occurrences about Hudson Bay or with those about Lake Ontario. The strata are highly fossiliferous and the palaeontological evidence presented seems to prove that the seas in which the Niagara sediments of the Winnipeg basin and of Hudson Bay were deposited were practically continuous, while both were separated from the Temiscaming basin and the region to the southwest.

The Pleistocene history of the region seems to consist of a period of glaciation by a great ice-sheet, followed by a profound submergence, during which time the ocean invaded a large portion of the Ottawa valley forming a marine gulf rivaling in extent the similar invasions of the sea in Palaeozoic times. The direction of motion of the ice varies from S 7° W to S 18° W.

[1] American Journal of Science, Vol. III, March 1897, p. 177.

The report also contains much information concerning the fauna, flora, and timber resources of the district, and has appendices giving lists of elevations and catalogues of the Palaeozoic fossils.

FRANK D. ADAMS.

The Paleozoic Reticulate Sponges Constituting the Family Dictyospongidae. By JAMES HALL and JOHN M. CLARKE.

More than a year ago volume one of the Fifteenth Annual Report of the New York state geologist made its appearance. In the introduction to this report several papers were announced which were not included in the volume, one of them being a monograph of the Dictyospongidae. It is this monograph which has now been published as volume two of the report above mentioned. It also appears in another binding as Memoir II of the New York State Museum. Unfortunately the annual report of the state geologist does not contain the complete monograph, the descriptions and illustrations of Carboniferous species being omitted. This monograph has long been in preparation by Drs. Hall and Clarke, and the printing of it had only been begun at the time of Dr. Hall's death.

The dictyospongidae are an extinct family of hexactinellid sponges, whose nearest living representative is the delicate glass sponge, *Euplectella*, commonly known as the "venus flower basket." They lived in greatest abundance during later Devonian and early Carboniferous time, though their most ancient representatives occur far back in the Silurian. Their fossil remains are especially abundant in the sandstones of the Chemung formation in western New York, several extensive colonies of them having been discovered as they grew upon the ancient sea bottom. Notable collections of them have also been made in the Waverly sandstones in Ohio, and in the Keokuk shale at Crawfordsville, Ind., and from the last locality only, have specimens been found in which the spicular skeleton of the sponge has been preserved.

The variety of forms assumed by these interesting sponges is wonderful, and the earlier observers were at a loss to know where to place them in the zoölogical classification. Before their sponge nature had been definitely established by Whitfield in 1881, they had been described as cephalopods and as marine plants. In life these organisms must have been most beautiful objects, "with their manifold variety of

graceful and striking shapes, they were not the somber bodies we find them to be in the rocks, but formed the most delicately woven fabrics of glass, latticed vases, urns and cups of the rarest delicacy and beauty. They must have been, when denuded of their sarcode, among the most exquisite structures of the past, as their descendants are of the present. Nothing, for example, could have surpassed the graceful filigreed chalice of *Botryodictya ramosa*, with its slender, tufted pedicel expanding above with a cup ornamented with pendant pouches."

In the list of genera and species, twenty-eight genera and one hundred and twenty eight species of these organisms are recognized, a great majority of them being here described for the first time. These descriptions of genera and species, with the introductory portion of the volume, fill two hundred quarto pages of text, and they are illustrated by seventy finely executed lithographic plates.

S. W.

Geological Report on Isle Royale, Michigan. By ALFRED C. LANE. Geological Survey of Michigan, Vol. VI, Part I. Lansing, 1898, pp. i + 281. 16 plates, 29 figures, 13 tables.

The report begins with a historical sketch of the mining operations from pre-historic times to the present. This is followed by a description of the method of constructing cross sections of the country from drill records, and this by an account of the succession of rocks forming the island, involving a detailed statement of the rocks traversed by sixteen drill holes. The results are compared with Irving's cross sections of Keweenaw Point, and the conclusion reached that there is represented on the Isle Royale practically the whole of the copper range as it exists from the Central mine to Portage Lake. A comparison is made with the Minnesota section with less definite results.

The portion of the report of more general interest is that which treats of the grain of rocks, both the theoretical discussion and the application of the theory to the rocks under investigation. The discussion opens with the consideration of conditions that affect cooling of molten magmas. Laws controlling the loss of heat are expressed mathematically, and diagrams are constructed exhibiting rates of cooling under various conditions. Deductions regarding the variations

in the grain of rocks corresponding to these conditions are exceedingly important and interesting. Some of the theoretical deductions are as follows : (1) After the temperature at the center of an intruded magma has fallen about one fourth of the interval between the initial temperature and the marginal temperature, the rate of cooling at a given temperature is the same for all parts of the sheet. (2) If the initial temperature (of intrusion) and conditions of cooling are such that a considerable time elapses before any part of the sheet reaches the point of solidification, the rate of cooling will be the same at all points, and, so far as the grain is dependent on it, there will be no change of grain, but the grain will be uniform from margin to center. (3) The hotter the dike or sheet initially, the less will be the width of the marginal zones of gradually finer grain ; also, the hotter the country rock, the less pronounced will be the marginal zone of finer grain. (4) The time of cooling varies as the square of the thickness of the dike or sheet, so that a dike 200 feet thick will cool four times as slowly, other things being equal, as a dike 100 feet thick. (5) Before the center (of an intruded mass) begins to cool off, the time required for a given loss of temperature for any point will vary as the square of its distance from the margin.

In applying the theory to the rocks examined it was found that some minerals, such as augite and feldspar, conformed fairly with theoretical requirements. In the case of sheets which have solidified before the center had appreciably cooled, it was found that "the area of cross sections or surface of the grains varies directly as the slowness of cooling." Again, " the linear dimensions of the augite patches (in the ophites, are directly as the distance from the margin."

With regard to the effect of chemical composition on grain, it is announced that " other things being equal, the greater the abundance of its constituent molecules, the coarser the grain of any mineral."

In conclusion, Dr. Lane ventures the prophecy "that it will prove widely true that superficial (extrusive) basic rocks are characterized by an increase of grain to near the center, while deep-seated basic rocks have a broad central zone of nearly uniform grain." He remarks in connection with the question of the effect of geological environment upon rocks that "it must also be remembered that the possession and loss of gas by diffusion follow the same laws as the possession and loss of the imponderable 'caloric,' while the possession of gas may greatly lower the temperature of solidification as glass."

The report closes with chapters on the petrography of the rocks; on the topography and Quaternary geology; the stratigraphy; and the chemical problems which are treated briefly. The last chapter is devoted to diabases, probably Keweenawan, intrusive in the Huronian. Among various interesting observations made in connection with these rocks is the conclusion that the micropegmatitic (micographic) intergrowth of quartz and feldspar found in some of them is undoubtedly a primary cystallization, and not a result of alteration in the rock.

J. P. I.

The Department of Geology and Natural Resources of Indiana. Twenty-third Annual Report. By GEORGE H. ASHLEY, Ph.D., Assistant State Geologist.

The report consists of 1741 pages, the first 1573 of which are devoted to the coals and coal area of the state. The state geologist, Mr. W. S. Blatchley, is to be congratulated on having secured, for this work of such importance to the state, the services of so painstaking and energetic a worker as Dr. Ashley.

The primary idea of the author seems to have been to make the report of the greatest possible value to those interested in the coal industry. Nevertheless it discloses much that is new concerning the structure of the southwestern part of the state, and throws light on the physical conditions that attended the formation of the Coal Measures of the eastern interior coal field.

Instead of using the letters of the alphabet to designate the different coal beds, as is done by Mr. Cox in the Seventh Annual Report, or Arabic numerals, as was done in the Illinois and Kentucky reports, the author has made use of Roman numerals, each of which denotes a division of the Coal Measures. There are eight of these divisions, numbered from below upward. In those localities, where a division includes more than one coal bed, the small letters of the alphabet are brought into use. For example, the three coals of Division v are designated v, va, vb. This method seems to present the advantage of at all times denoting the exact horizon under consideration, and of locating the beds of small area.

The organization of the volume divides it into four parts. Part I dealing with the Geology of Coal; Part II, with the General Geology

of the Coal Measures of Indiana; Part III, with the Detailed Geology of the Indiana Coal Field; and Part IV, with Mines, Mining, and the Utilization of Coal. In Part III the method of treatment is by counties.

Probably the best feature of the report is to be found in the excellent illustrations, which consist of 986 figures, 91 plates, and 7 maps. Especially are the maps and the accompanying sections to be commended.

The latter part of the volume is devoted to reports of the inspector of mines and the natural gas supervisor.

A. H. PURDUE.

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United States Geological Survey. Monograph XXXI. Geology of the Aspen Mining District, Colorado, with Atlas. JOSIAH EDWARD SPURR. Samuel Franklin Emmons, geologist in charge.

The monograph is primarily concerned with the economic interests of the Aspen district. But it also contains much that is of general scientific interest. Mr. Emmons contributes the introduction, but the body of the monograph is the work of Mr. Spurr. The volume is profusely illustrated and the accompanying atlas contains sheets giving the general geology and topography of the district, besides eight special sheets giving the detailed geology of limited areas. It also contains numerous sections constructed on an elaborate scale, which make the complex faulting intelligible. Both the monograph and its accompanying atlas exemplify the magnificent execution characteristic of the United States Geological Survey.

Great interest attaches to the author's study of faults as set forth in this work. Aspen seems to have furnished a field quite worthy of his best endeavor. Some of the sheets presented in the atlas seem like inextricable puzzles; but this special student of faults straightens out the "crazy-work" in an admirable way and makes it all intelligible. It is of interest to note the fact that movement along some of the faulting plains is taking place at the present time at a rate which requires recognition in the practical operations of mining.

Under "Chemical Geology" some observations are given which throw light on the vexed question of dolomization. The origin and change of ores is also discussed.

W. T. Lee.

Geological Survey of Georgia. W. S. Yeates, State Geologist. *Bulletin No. 7, A Preliminary Report on the Artesian-Well System of Georgia.* By S. W. McCallie, Assistant Geologist. State Printer, Atlanta, Ga., 1898, pp. 214.

One of the significant signs of growing wisdom in the administration of state surveys is the increased attention given to common resources of wide interest as distinguished from rich deposits of immediate value to a fortunate few only. Among these resources of common interest is the water supply which admits of successful treatment on a scientific basis, whether in the form of flowing wells or otherwise. In real importance it transcends many of the more impressive subjects. The present treaties is an excellent expression of this commendable policy. The first thirty pages are devoted to a clear exposition of the essential conditions of successful artesian wells and practical considerations relative to them. This is well illustrated. The rest of the volume is devoted to the special consideration of the artesian wells of Georgia, in which much data of general geological interest is incidentally included. Large artesian resourses are shown. While full data are not obtainable, it is clear that notable improvement in public health has resulted from the use of these wells. T. C. C.

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THE

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SIR WILLIAM DAWSON.

In Sir William Dawson there has passed away the last survivor of that distinguished group of naturalists which in the earlier part of this century achieved for science in America such brilliant results and such widespread recognition—men whose range of knowledge was almost encyclopedic, and many of whom made valuable contributions to science in widely separated fields. The environment of the man of science has now changed, and the older type of naturalist seems unfortunately about to disappear.

Sir John William Dawson was from near Nova Scotia, a province which has produced more than its share of the Canadians who have risen to eminence in the various walks of life, having been born at Pictou on October 13, 1820. He died at Montreal on November 19, 1899, at the age of 79.

His father, James Dawson, was from near Aberdeen, Scotland, and came to Nova Scotia to fill a position in a leading business house in Pictou, and on the termination of his engagement began business there as a shipbuilder on his own account.

While still at school in Pictou, at the age of 12, he developed a love for natural science, inherited from his father, and made large collections of fossil plants from the Nova Scotia Coal Measures, so well exposed about his native place. He speaks of

himself at that time as being a "moderately diligent, but not a specially brilliant pupil." On leaving school he studied at Pictou college, and subsequently at the University of Edinburgh. While at the former seat of learning, at the age of 16, he read before the local Natural History Society his first paper, having the somewhat ambitious title "On the Structure and History of the Earth." He returned to Nova Scotia in 1847, and two years later went to Halifax to give a course of lectures on natural history subjects in connection with Dalhousie College, and organized classes for practical work in mineralogy and paleontology. These were attended by students, citizens, and pupils of higher schools, a foreshadowing of university extension. In 1850, at the age of 30, having already attracted some attention by the publication of a number of papers, reports, and lectures, he was appointed Superintendent of Education for Nova Scotia. From this time he became known in his native province as an indefatigable promoter of educational progress, and a founder of educational institutions. His work in connection with this position obliged him to travel continually through all parts of the province, and on these journeys he accumulated that immense mass of information concerning the geology and mineral resources of Nova Scotia which are incorporated in his largest work—that entitled Acadian Geology.

Sir Charles Lyell, in 1841, on his first visit to America, met Sir William, and was by him conducted to many places of geological interest in Nova Scotia, and on his subsequent visit in 1852 they together continued their studies in Nova Scotian geology. In a letter to Leonard Horner, dated September 12 of this year, Lyell writes:

"My companion, J. W. Dawson, is continually referring to the curious botanical points respecting calamites, endogenites, and other coal plants, on which light is thrown by certain specimens collected by him at Pictou. He told me that the root of the pond lily, Nymphæa Odorata, most resembled Stigmaria in the regularity of its growth, and Dr. Robb showed me a dried specimen, a rhizoma, which being of a totally different family, and

therefore not strictly like, still suggests the probability of the Stigmaria having grown in slush in like manner." And in another part of the same letter, referring to the now celebrated Joggins section on the coast of Nova Scotia, he says: "Dawson and I set to work and measured, foot by foot, many hundred yards of the cliffs, where forests of erect trees and calamites most abound. It was hard work, as the wind one day was stormy and we had to look sharp lest the rocking of living trees, just ready to fall from the top of the undermined cliff, should cause some of the old fossil ones to come down upon us by the run. But I never enjoyed the reading of a marvelous chapter of the big volume more. We missed a botanical aid-de-camp much when we came to the tops and bottoms of calamites and all sorts of strange pranks which some of the compressed trees played."

About this time the governing body of McGill College at Montreal was looking about for some one fitted to assume the principalship of the institution and to reorganize it.

The college, founded by Royal Charter in 1821, had made but slow progress in its earlier years, and was at this time, through litigation and other causes, almost in a state of collapse. Sir William, then Mr. Dawson, was pointed out to the Governors of the College by Sir Edmund Head, then Governor General of Canada, as a man who, if his services could be secured, was eminently fitted to undertake the task of reconstructing the university. In the meantime, ignorant of all this, he was prosecuting a candidature for the chair of Natural History in his alma mater, the University of Edinburgh, rendered vacant by the death of Professor Edward Forbes, and in which he was strongly supported by the leading geologists of the time. By a strange coincidence, just as he was about to leave Halifax for England in connection with this candidature, intelligence arrived that the Edinburgh chair had been filled at an earlier date than his friends had anticipated, and at the same time a letter was received offering him the principalship of McGill.

The services of Dr. Dawson were accordingly secured, and in 1855 he assumed the principalship of McGill College, stipulating

at the same time that the chair of Natural History should be assigned to him. In his inaugural discourse he said: "At a time when literary and scientific pursuits are so widely ramified everyone who aims to do anything well must have his special field of activity. Mine has been the study of nature, especially in those bygone aspects which it is the province of geology to investigate. My only other special qualification for my present position depends on the circumstance that the wants of my native province have induced me to devote much time to inquiries and pursuits relating to popular education. I come to you, therefore, as a naturalist and an educationalist, trusting that I may be enabled in these capacities to render myself useful, and asking for my youth and present inexperience in the affairs of this institution your kind indulgence, and for the work in which I shall be engaged your zealous coöperation."

The University as he found it had three faculties and but sixteen professors, a number of whom gave only a portion of their time to university work, while the buildings and equipment were wretched. When it is stated that the University has now 120 professors and instructors of various grades and an equipment which is in all departments fairly good, and, in some of them, unsurpassed, some idea may be gained of the progress which the institution made under Sir William Dawson's care and guidance.

As a professor of natural science Sir William at this time delivered courses in chemistry, botany, zoölogy, and geology, and natural science became a very favorite study among the students, for he was an excellent lecturer, and his enthusiasm for these studies was communicated to all who heard him. As years went on, the instruction in the first three of these subjects was undertaken by others, and a special chair of Geology and Paleontology was endowed by his old friend and co-worker, Sir William Logan, a chair which he held until his final retirement. His teaching work, however, formed but a small part of his daily labors. In addition to administering the affairs of the University he was first and foremost in every movement to

further education in the province, and no educational board was complete without him. He was the honorary president of the Natural History Society and never missed a meeting or a field day, and also identified himself closely with many other societies in Montreal, and spared neither time nor labor on their behalf.

Over and above all this he found time to carry out original work along several lines, achieving most valuable results, as well as to write many popular works on science, more especially in its relation to religion. Original investigation he always considered to be one of the chief duties and pleasures of a man of science. Most of his work along these lines was done during his summer vacations; in fact he was led to accept the position of principal in McGill chiefly by the fact that the vacations gave him leisure and opportunity for work of this kind.

He was always very progressive in his ideas relative to the scope and development of university teaching, and was continually urging the endowment of new chairs and the broadening of university work, so that all young men wishing to train themselves for the higher walks of life might in the university find their needs supplied. As an instance of this it may be mentioned that so far back as 1858 he succeeded in establishing a school of civil engineering, which, after a severe struggle for five years, succumbed to some unfriendly legislation, only, however, to be revived by him in 1871 and developed into the present faculty of applied science of McGill University, with its numerous departments, its full staff of instructors and excellent equipment. Sir William, furthermore, never hesitated, if funds were not forthcoming in sufficient amount for these purposes, to subscribe large sums out of his own limited private means, and he was also the continual helper of needy students desiring to avail themselves of the University's teaching.

Sir William received the degree of M.A. from the University of Edinburgh in 1856, and the degree of LL.D. from the same University in 1884. His attainments and the value of his contributions to science were widely recognized, and he was elected

an honorary or corresponding member of many learned societies on both sides of the Atlantic. He was made a Fellow of the Geological Society of London in 1854 and of the Royal Society in 1862. In 1882 he was invited by Lord Lorne to aid in the organization of the Royal Society of Canada as its first president. He was also President of the Geological Society of America and of both the American and British Associations for the Advancement of Science. In 1884 he received the honor of knighthood.

After a long life of continuous labor, Sir William's health, in 1892, became seriously impaired, and it became necessary for him to lay aside his work for a time and spend a winter in the South. Failing to recover his strength, however, he resigned his position as principal in June 1893, and retired from active work. During the later years of his life his strength gradually ebbed away, and what little work he could undertake consisted in arranging his collections and working up some unfinished papers. Several of these were published in 1894 and 1895, but the years of quiet labor in his favorite pursuits, to which he looked forward at this time, were cut short by a series of sharp attacks, culminating in partial paralysis, which forbade further effort. During the last few years, from time to time, his strength rallied somewhat and he attempted to resume his work. Only a few days before his death he penned a short essay on the "Gold of Ophir." He passed away on the 19th of last month, very peacefully and without pain. We may say, in the words of Dr. Peterson, his successor in the principalship of the University, "For such a painless passing out of life no note of sorrow need be struck. There is no sting in a death like his; the grave is not his conqueror. Rather has death been swallowed up in victory — the victory of a full and complete life, marked by earnest endeavor, untiring industry, continuous devotion and self-sacrifice, together with an abiding and ever-present sense of dependence on the will of heaven. His work was done, to quote the great Puritan's noble line, 'As ever in his great Taskmaster's eye.'"

Lady Dawson, with three sons and two daughters, survive him, of whom the eldest, Dr. George M. Dawson, the present director of the Geological Survey of Canada, has inherited his father's love for geological studies, and has achieved wide distinction in the world of science.

Sir William's first original contribution to science was a paper read before the Wernerian Society of Edinburgh in 1841, on a species of field mouse found in Nova Scotia. From that time onward he was a continuous contributor to scientific journals and to the publications of various learned societies. His papers were very numerous and covered a wide range of subjects in the domain of natural history. No less than 158 titles are recorded under his name in the Royal Society's catalogue; and in a bibliography which he prepared for the Royal Society of Canada in 1895, and which included only books and papers of the first importance, 128 titles are recorded. He contributed over 100 papers to the publications of the Montreal Natural History Society alone. His complete bibliography, now in course of preparation, will certainly include several hundred contributions. The most important work of his earlier years was an extended study of the geology of the maritime provinces of the Dominion of Canada. His results are embodied in his *Acadian Geology*, already mentioned, a volume of nearly 1000 pages, accompanied by a colored geological map of Nova Scotia, which has passed through four editions. In writing to Sir William in 1868, Sir Charles Lyell says of this work: "I have been reading it steadily and with increased pleasure and profit. It is so full of original observation and sound theoretical views that it must, I think, make its way, and will certainly be highly prized by the more advanced scientific readers." It is the most complete account which we have of the geology of Nova Scotia, New Brunswick, and Prince Edward's Island, although since it appeared large portions of these provinces have been mapped in detail by the Geological Survey of Canada, and Sir William's conclusions modified in some particulars. In carrying out this work Sir William paid especial attention to the paleontology of the

Carboniferous system, and to the whole question of the nature and mode of accumulation of coal. He subsequently studied the paleontology of the Devonian and Upper Silurian systems of Canada, discovering many new and important forms of plant life. In 1884 he began the study of the Cretaceous and Tertiary fossil plants of western Canada, and published the first of a series of papers on the successive floras from the lower Cretaceous onwards, which appeared in the *Transactions of the Royal Society of Canada.* He also contributed a volume entitled *The Geological History of Plants* to Appleton's International Scientific Series. In 1863 he published his *Air Breathers of the Coal Period,* in which were collected the results of many years' study in the fossil batrachians and the land animals of the Coal Measures of Nova Scotia. The earliest known remains of microsauria were then discovered by him in the interior of decayed tree stumps in the Coal Measures of South Joggins. The results of his later studies in these creatures were embodied in a series of subsequent papers which appeared from time to time.

On taking up his residence in Montreal his attention was attracted by the remarkable development of Pleistocene deposits exposed in the vicinity of the city, and he undertook a detailed study of them, and especially of the remarkably rich fossil fauna which they contain. He also studied subsequently the Pleistocene deposits of the lower St. Lawrence, and instituted comparisons between them and the present fauna of the Gulf of St. Lawrence and of the Labrador coast. The results of these studies appeared in a series of papers as the work progressed, and were finally embodied in a volume entitled *The Canadian Ice Age,* which was issued in 1893 as one of the publications of the Peter Redpath Museum of McGill University. This is one of the most important contributions to the paleontology of the Pleistocene which has hitherto appeared.

Sir William's name is also associated with the renowned Eozoon Canadense, discovered by the Geological Survey of Canada in the Grenville limestones of the Canadian Laurentian, and described by him in 1864 as a gigantic foraminifer.

Concerning this remarkable object there has been a widespread controversy and a great divergence of opinion. Some of the most experienced observers in the lower forms of life, such as Carpenter, accepted it as of organic origin, while others considered it to be inorganic, and while the balance of opinion now possibly favors the latter view, its resemblance microscopically to certain organic forms is certainly most remarkable. The literature of this subject, which includes many papers by Sir William, is quite voluminous, but the chief facts are summed up in his book, entitled *The Dawn of Life*, which appeared in 1875.

Sir William was also a prolific writer of popular works on various geological topics. Among these may be mentioned *Fossil Men and Their Modern Representatives*, *The Chain of Life in Geological Time*, *Egypt and Syria their Geology and Physical Geography in Bible History*, *Modern Science in Bible Lands*, *Modern Ideas of Evolution*, *Salient Points in the Science of the Earth*, *Eden Lost and Won*, and *Relics of Primeval Life*. As may be inferred from their titles, many of these books display a strong theological bias. Sir William was a Presbyterian of the old school and strongly opposed to all theories of the evolution of man from brute ancestors, nor would he allow anything more than a very moderate antiquity for the species. He held that there is no adequate reason for attributing the so-called "Neolithic" man to any time older than that of the early eastern empires, while he thought the time for Paleolithic man need not be more than twenty or thirty centuries in addition, man having thus made an abrupt appearance in full perfection not more than, say, six or eight thousand years ago.

These works on the relation of science and religion met a popular need and were of great comfort to many a pious soul, who feared that the whole framework of faith was being swept away by the advancement of science. Their value, however, was not permanent, and they are not the works by which Sir William Dawson will be remembered. His reputation is founded on the great contributions to our permanent stock of knowledge which he has made and which are embodied in his works on pure

science, representing achievements of which any man might well be proud.

Sir William had a courteous, or rather a courtly, manner, based on a genuine consideration for all. He was respected and beloved by all who knew him, and especially endeared himself to all who studied under him. The preëminent note of his character was simplicity and singleness of purpose. His loss will be felt especially in the institution with which he was long connected, but his name has been perpetuated in connection with the geological department of his university by the establishment of a second chair in geology, to be known as the Dawson Chair, which has just been endowed in his memory by Sir William Macdonald.

FRANK D. ADAMS.

GRANITE ROCKS OF BUTTE, MONT., AND VICINITY[1]

In the western mountainous part of Montana there are several extensive areas of granitic rocks, which are commonly surrounded by sedimentary beds and in part covered by later volcanic rocks. The largest of these granite masses forms a mountainous area having no commanding summits, but constituting the continental water parting separating the waters of the Atlantic from those tributary to the Pacific Ocean. This district is largely drained by the Boulder River, and as the mountains have no other name, they too are sometimes called by this name, for which reason it will be used to designate the intrusive mass of granite itself. Unmistakable evidences of intrusion are common about its borders, and as the rock cuts and metamorphoses fossiliferous Carboniferous rocks and what are believed to be Cretaceous rocks as well, and is overlaid by Neocene sediments, its age is known within these limits.

The Boulder batholith is a body of granitic rock, in part covered by later lavas, but continuously exposed from the Highland Mountains (sixteen miles south of Butte) to the vicinity of Helena, a distance of fifty miles in a north and south direction and twenty-four miles from east to west. The intrusive nature of the mass is very strikingly shown at the northern and southern limits, and also at Elkhorn on the east. At these places the granitic rocks have produced very marked contact metamorphism, and cut across the ends of the upturned sedimentary series. Near its border the granite also includes in its mass fragments of the other rocks. There is no suggestion of a laccolithic uplifting, for although near Helena, and probably elsewhere, the granitic rocks extend outward under the sedimentary rocks, and the latter in certain places form a thin cover over the intrusion, yet the strata dip toward the intrusion conformable to a great anticlinal uplift wholly independent of the batholith.

[1] Published by permission of the Director of the U. S. Geological Survey.

The rocks of this batholith present a wide variation in mineral and chemical composition, but a study of the field relations shows they must be regarded not only as facies of the same magma, but as parts of one mass. The very basic rocks all occur at the margins, yet there are variations within the main body itself which are clearly recognizable rock types, yet cannot be discriminated in mapping. This difficulty has been experienced by those geologists working in the Sierra Nevada, where, as stated by Turner,[1] a considerable variety of rock-types have been mapped as granodiorite, "although, as a rule, gabbro, even when genetically related to granodiorite proper, has been separated.' Where detailed mapping upon a large scale map is not possible, this difficulty of separating parts of a single intrusive body in which the rock-types grade into one another can only be met by an arbitrary use of the name of the prevailing rock-type for the entire mass, as has commonly been done heretofore, or by using a generic term like granolite[2] to embrace all coarsely granular rocks.

The prevailing rock of the batholith is a granite whose composition is that given under the number 518. It is a normal hornblende-granite which is very generally sheeted, forming picturesque crags and bowlder groupings. It disintegrates readily into platy masses or shells which separate from the bowlders, and themselves crumble to a coarse sand. Over large tracts disintegration has reduced the rock to a smoothly rolling surface, on which scattered bowlders rise above the general level. Perfectly fresh material can, therefore, be obtained only where the rock has been quarried or exposed by mining operations. It is a medium to coarse-grained rock, the average size of the grains being 3–5 mm. The grayish quartz and white feldspar grains are of about equal size. Black mica and dark green hornblende are present in considerable quantity. Under the microscope it shows the normal characters of a granite, but contains an unusual amount of plagioclase.

[1] H. W. TURNER: Granitic rocks of Sierra Nevada, JOUR. GEOL., Vol. VII, 1899, p. 146.

[2] See TURNER: loc. cit., p. 141.

In the following table the results are given of the analyses so far made of the rocks of the Boulder batholith:

ANALYSES OF ROCKS FROM THE POST-CRETACEOUS GRANITIC BATHOLITH OF THE BOULDER MOUNTAINS, MONTANA

				Butte granite						Aplites	
	526	525	130	311	623	6	989	98	518	640	951
SiO_2	49.22	56.41	61.64	63.87	63.88	64.05	64.34	64.17	67.12	76.87	77.05
TiO_2	0.95	0.68	.71	.65	.65	.60	.53	.67	.48	.11	.12
Al_2O_3	12.02	17.62	15.63	15.39	15.84	15.38	15.72	15.25	15.00	12.52	12.84
Fe_2O_3	2.77	1.24	3.39	1.93	2.11	2.20	1.62	2.16	1.62	0.67	.56
FeO	8.80	3.55	2.69	3.08	2.59	2.74	2.94	2.98	2.23	none	.14
MnO	tr	.08	.04	.11	.07	.11	.12	.04	.06	...	none
CaO	10.56	8.66	4.90	4.30	3.97	4.30	4.24	4.24	3.43	0.49	.57
MgO	9.29	3.97	2.82	2.23	2.13	2.08	2.17	2.60	1.74	0.09	tr
K_2O	1.70	2.61	3.72	4.18	4.23	4.00	4.04	4.34	4.52	5.78	5.52
Na_2O	1.90	3.35	2.64	2.76	2.81	2.74	2.76	2.62	2.76	2.47	2.81
H_2O below 110°	0.27	.14	.28	.19	.22	.27	.25	.16	.09	0.25	.22
H_2O above 110°	1.63	.76	.91	.69	.66	.83	.76	.65	.58	0.52	.48
BaO	.03	.09	.08	.07	.09	.08	.06	.07	.07	...	none
SrO	.03	.08	.04	.04	.02	.04	.03	tr	.03	...	none
P_2O_5	0.43	.49	.21	.17	.21	.21	.14	.16	.15	.05	none
Cl	.08	.07	...	...	...	...	...	tr	...	...	...
S	.05	...	...	.07	...	.07	.03	...	...	...	none
SO_3	.04	...	none	...	...	...	...	.07	tr	...	...
CO_2	...	...	none	.15	...	.35	.03	none	none	...	none
Totals	99.77	99.70	99.70	99.91	99.72	100.05	99.80	100.18	99.88	99.82	100.31

H. N. Stokes, Analyst.

526, 525. Contact facies of granite mass, Red Mountains.

130. Diorite, Red Rock Creek, intrusive in batholith.

311, 623, 6, 989. Butte type of granite, Butte district.

98. Head of Clancey Creek, northern part of batholith.

518. Prevailing type of granite of batholith, Boulder.

640, 951. Aplites of Butte granite, Butte.

The following table shows the chemical composition of this rock, only the essential elements being given, the complete analysis being shown in the preceding table. Partial analyses of quartz-monzonite from the Sierra Nevada[1] and of Brögger's adamellite[2] are given for comparison.

[1] H. W. TURNER: The granitic rocks of the Sierra Nevada, JOUR. GEOL., May 1899, p. 141.

[2] Die eruptionsfolge der triadischer Eruptivgesteine bei Predazzo, p. 62.

	Boulder Granite	Quartz Monzonite	Granodiorite	Adamellite
		2179 Sierra Nevada	Pyramid Peak	Landsberg bei Barr Vogesen Rosenbusch
SiO_2	67.12	66.83	67.45	68.97
Al_2O_3	15.	15.24	15.51	14.80
CaO	3.43	3.59	3.60	3.82
MgO	1.74	1.63	1.10	1.15
K_2O	4.52	4.46	3.66	4.53
Na_2O	2.76	3.10	3.47	2.40

The close similarity of this rock to the quartz-monzonites of the Sierra Nevada is apparent from these figures. It is evident from the analyses that the Boulder granite nearly corresponds to Brögger's adamellite.

THE BUTTE GRANITE

The Butte granite (or quartz-monzonite) covers an area of several square miles and is the prevailing rock of the Butte district, and the one in which the world-famous copper and silver veins of that place occur. It is, therefore, of more than ordinary interest, and has been carefully investigated in connection with the study made of the general and economic geology of the district. It is a rather dark colored, coarsely granular rock which is seldom seen in conspicuous exposures about the productive mines owing to a close sheeting with much decomposition near the mineral veins and ready disintegration in other parts of the district. Away from the mineralized areas it is well sheeted and forms the usual bowlder and castellated forms of such rocks. Its darker tone and greenish feldspars render it easily distinguished from the bowlder type. Throughout the entire district it is very uniform in appearance, as it proves upon analysis to be in composition, though differing somewhat in the relative proportions of the constituent minerals. It is also uniform in grain over the entire district, but hand specimens show in local patches a variation of textures. Inclusions of a much darker and finer-grained dioritic rock are often seen weathered in relief on exposed surfaces; they are always small, seldom over a few inches across, angular and rather scarce, never making an appreciable part of

the mass. Owing to disintegration prefectly fresh specimens can only be obtained from surface quarries or underground workings. The exact relations of this mass to the general area were not satisfactorily determined, though it appears certain from the exposures that it is an integral part of the batholith and not a separate intrusion. At several localities a sharp gradation was observed, with narrow transition bands between the lighter colored granite with its white feldspars and the darker Butte type.

Orthoclase is an abundant and usually a readily recognizable constituent as its pinkish color is in contrast to the green tones of the plagioclase, and it has, moreover, a tendency to develop in relatively large crystals which give the rock a somewhat porphyritic look. Plagioclase, black hornblende, black biotite, and quartz are easily distinguished by the eye. Under the microscope the rock is seen to vary between a rather basic hornblende-granitite and a quartz-diorite. There is usually a slight amount of chlorite present, but the biotite and hornblende are as a rule fresh. Titanite, apatite, iron ore, and zircon are present as accessories. It will be seen that the rock is only a somewhat more basic phase of the granite of the region, and that it closely resembles granodiorite, though in the Butte rock the plagioclase is more basic, being a sodic labradorite. The four analyses given in the general table show the rock to be remarkably uniform in chemical composition over the entire area.

The following table gives partial analyses of the Butte granite and of the related rocks from other localities :

PARTIAL ANALYSES OF BUTTE GRANITE AND RELATED ROCKS

	Butte (average)		Granodiorite (average)	Boise	Banatite (average)		Boulder
SiO_2	64.03		65.48	65.25	64.39		67.12
Al_2O_3	15.58		16.05	16.94	15.90		15.
Fe_2O_3	1.96		1.47	1.60	5.63		1.62
FeO	2.83		3.02	1.91			2.23
CaO	4.20		4.80	3.85	4.15		3.43
MgO	2.15		2.13	1.31	1.93		1.74
K_2O	4.11	6.87	2.43	3.02	3.57	7.05	4.52
Na_2O	2.76		3.49	3.57	3.49		2.76

The analysis of the Butte rock is the mean of the four analyses already given. The granodiorite is the mean of five analyses given by Turner.[1] The Boise rock is described by Lindgren.[2] The Banatite is a mean of the analyses quoted by Brögger.[3] From the analyses it will be seen that the rock closely resembles a banatite in composition; the lime and sum total of the alkalis being the same, but in the Butte rock the potash exceeds the soda in amount. It also resembles the granodiorites, but the alkalies present an inverse ratio.

In order to furnish a basis for calculating the mineral composition of this rock, fresh rock was crushed, the hornblende and biotite separated by Dr. H. N. Stokes by the use of Thoulet solution, and these two minerals from each other by sliding on paper. The resulting material was examined under the microscope and found to be quite pure.

The biotite is quite black in color to the eye, but dark brown under the microscope showing very marked pleochroism. This biotite is characteristic not only of the Butte granite but of the Boulder granite as well. In many sections examined it appears the same in color and pleochroism not only for the Butte rock but for the normal granite of the batholith, and it may be assumed to be the same for both these rocks. The microscopic examination of the biotite material showed a little apatite present, a very little chlorite, and very little hornblende, but these impurities form a very minute part of the whole. The amphibole is also characteristic of both the Butte granite and the normal granite of the region. It is black or very dark green when seen with a hand lens, but pleochroic in dark green tints with large extinction angle when seen under the microscope. The material analyzed was very pure.

The following table shows the result of the analyses made of these minerals. Dr. Stokes was unable to obtain a higher

[1] Loc. cit., p. 150.

[2] Mining Districts of the Idaho Basin and Boise Ridge, Idaho. Eighteenth Ann. Rept. Director U. S. G. S. 1898, p. 740.

[3] Loc. cit., p. 62.

summation in the analyses made of each, and the amount of material available being exhausted further work could not be done. For reference the analyses published by Turner of the biotite and amphibole from the quartz-monzonite of the Sierra Nevada, are also given.[1] The close resemblance of the analyses of both rocks and minerals to those of the Butte material will be noted.

	Biotite		Hornblende		Butte granite
	Butte	S N 2652	Butte	S N 2652	
SiO_2	35.79	35.75	45.73	47.49	64.03
TiO_2	3.51	3.16	1.43	1.21	.60
P_2O_5	.10	.03	.28	.06	.18
F	.76	.17	....	....	.....
Cl	.20	....	....	....	.....
Al_2O_3	13.70	14.70	6.77	7.07	15.58
Fe_2O_3	5.22	4.65	4.94	4.88	1.96
FeO	13.72	14.08	10.30	10.69	2.83
MnO	.19	.45	.54	.51	.11
BaO	.13	....	none	....	.07
SrO	none	.12	none	....	.04
CaO	.05	.17	11.25	11.92	4.20
MgO	12.13	12.37	12.32	13.06	2.15
K_2O	9.09	9.19	1.22	.49	4.11
Na_2O	.15	.32	.77	.75	2.76
Li_2O	tr	tr	tr	tr	.....
H_2O below 110°	1.21	1.03	.49	....	.20
H_2O above 110°	3.64	3.64	2.29	1.86	.73
Total	99.59	100.00	98.77	100.03	99.87
Less O for F & Cl	.37		.12		
	99.22 Stokes	Hillebrand	98.65 Stokes	Hillebrand	Stokes

The Butte analyses are incomplete as the amount of material was too small for further work.

The phosphoric pentoxide (P_2O_5) in the analyses of both minerals and of the rock itself is assumed to be present as apatite and with an appropriate amount of lime is deducted from the analyses. The water below 110° C. is assumed to be accidental and is also deducted. The analyses are then reduced to 100, and the molecular ratios calculated.

[1] Some rock forming biotites and amphiboles. A. J. Sci. Vol. VII, 1899, p. 294.

All the soda is calculated as albite. Microscopic examination shows the plagioclase to be a calcic andesine Ab_1, An_1, and, an estimate being made of the proportion of hornblende present, an equivalent amount of lime is deducted and the remainder calculated with the albite molecule to form plagioclase.

The result gives the following composition for the rock:

	I	II
Quartz	23.70	20.8
Orthoclase	19.88	18.
Albite	22.98	28.
Anorthite	11.48	12.1
Hornblende	15.26	16.6
Biotite	4.22	—
Magnetite	1.18	1.5
Titanite	.97	1.4
Apatite	.33	.3
	100.00	98.7

This adds up to 1.51 molecular weight against 1.50 for the bulk analysis of the rock, showing a very close agreement. As the microscope shows the plagioclase to be andesine of about the composition of Ab_1, An_1 (or Sodic labradorite), and albite is not seen in the section, the orthoclase must contain the albite molecule. In the second column the percentages given are those calculated by Lindgren[1] for the granodiorite of Grass Valley—a rock whose chemical analysis, as already shown, closely resembles that of the Butte granite.

The rocks in the vicinity of the Frohner mine are identical in composition with the Butte granite, as shown by the analysis. The region is about thirty miles north of Butte, and the rock part of the general granite batholith.

THE BLUEBIRD APLITE

Associated with the Butte granite there is an unusual development of aplite. So far as known to the writer it is the most extensive occurrence of a granite aplite yet discovered. The

[1] Gold Quartz Veins of Grass Valley, Cal., Seventeenth Ann. Rep. Dir. U. S. Geol. Surv., p. 42.

largest mass is 1¼ miles by $2\frac{1}{16}$ miles, and is known from mine workings to be several hundred feet thick, resting on the Butte granite. Besides this large mass there is another of about one-third the size and numerous smaller bodies, as outlined by the author on the geologic map of the Butte district. In the cases hitherto observed by the writer, and those commonly described, aplites occur in dikes commonly quite narrow, but often of considerable length; such masses have been supposed to be the filling of cracks formed in the cooling granite, the aplite magma coming either from an acid residuum or nucleus of the mass or, as suggested by Turner, a product squeezed out of the crystallizing granite and gathered in cracks due to its shrinkage. A study of the Butte aplites shows that, though the dikes of this material may owe their origin to some such cause, that the irregular lense-like or meniscoid masses are sometimes local bodies unconnected with any feeder. The inference derived from a careful examination of many exposures is that the material is due to some such process as that suggested by Turner—a sort of segregation. In the description of the remarkable differentiation zone of Square Butte[1] it was shown that the basic outer part of the intrusion, itself a product of differentiation, holds a thin band of white syenite due to further separation or differentiation of the feldspathic constituents in the crystallizing mass.

This hypothesis, my belief in which has been strengthened by further observations of other laccoliths in the same region, seems to explain the manner of occurrence of the aplites in the Butte mass. It is believed, upon evidence which cannot be presented here, that the Butte district is on the downthrown side of a fault and that its granitic rocks represent the upper part of the batholitic intrusion. In this uppermost part of the intrusion partial differentiation is believed to have taken place, the normal granite, represented by analysis No. 516, splitting up into the more basic phase represented by the Butte type and the acidic type, the Bluebird aplite. This hypothesis demands that as the Butte granite

[1] WEED and PIRSSON: Highwood Mountains of Montana, Bull. Geol. Soc. Am., p. 406, 1896.

is but slightly more basic than the prevailing form, the proportion of aplite should be small. The field observations show a quantitative relation which, as far as it can be estimated, confirms the view.

This hypothesis implies a gathering of the iron, magnesian, and lime molecules out of the general magma and their concentration in the quartz-monzonite, with a separation out of the aplitic material, richer in alumina, alkalis, and silica which did not form an inner kernel as it has in laccolithic differentiations, but local masses in the basic granite. This hypothesis has already been anticipated by Cross in the discussion of evidence of differentiation at Rosita, Colo.[1]

If the Butte granite is a border or upper contact facies of the batholith, this separation may have been induced by contact cooling. Observations of many of the smaller intrusive stocks of the Montana mountains and of the contacts of the larger batholiths show that there is more or less of a mixing of basic and siliceous materials as if they were stirred together while pasty. The rocks grade into one another and there are no sharp contacts.

In the large aplite intrusions there is no sahlband alteration. The grain continues the same in both rocks, but at a certain line there is a change in the relative proportions of the minerals. In the smaller bodies and little dikelets the grain of the aplite is finer, though there is no contact band or evidence of chilling. In the Butte area this is uncommon. There is, it is true, a sharp contact between granite and aplite, but there are transition forms and even masses of granite in the larger aplite bodies which are clearly not included fragments but integral parts of the mass. Yet there is commonly a definite separation of the two rocks, and it is certain that there has been no mixing of the two materials due to convection or movement before consolidation.

In most of the aplite bodies the grain varies considerably from place to place; sometimes the rock becomes a micropegmatite,

[1] Geology of Silver Cliff and Rosita Hills, Colo., Seventeenth Ann. Rep. Dir. U. S. Geol. Surv., p. 329.

rarely a coarse pegmatite. There is sometimes a banding with alternations of fine and coarse-grained material.

The commonly accepted theory of the origin of aplite is that it represents the acid remainder in a granite or quartz-diorite magma after the more basic elements have crystallized. At a late period, after the main mass of the granitoid rock had crystallized, the aplite is forced up from below and fills previously formed cracks, which are perhaps the result of cooling. Viewed in this light they are genetically related to the more basic granites with which in the Sierra Nevada they are for the most part directly associated.[1]

The aplite.—The following calculation of the mineral composition of the aplite, column I, is based upon the complete chemical analyses given in the table. A little biotite is found in the fresh aplite. This is similar to that of the granite and is supposed to have the same composition, and all the magnesia is ascribed to this. This leaves an excess of 0.09 of TiO_2, which is calculated as titanite.

	I	II
Quartz	37.70	39.45
Potash feldspar	33.90	29.43
Soda feldspar	23.81	23.03
Lime feldspar	2.45	6.56
Biotite	0.72	.90
Magnetite, etc.	1.20	.58
Titanite	0.22	.18
	100.00	100.00

In column II the mineral compositions of the aplites of the Granodiorite of the Sierra Nevada, given by Turner, are given for comparison.

LAMPROPHYRIC CONTACT FACIES

The first two analyses in the large table represent the compositions of two lamprophyric contact facies of the batholith. The rocks probably grade into the granite, though the transition is a

[1] H. W. TURNER: Geology of Sierra Nevada, p. 722.

rapid one. More often such rocks occur as intrusions in the altered sediments about the border of the batholith. The first analysis is that of a rock that might be called a diorite, though it hardly comes under that name. It consists mainly of green hornblende, which is stringy and appears to be derived from augite, and of small zonally built basic plagioclase feldspars and a very little quartz. It is a nearly black, quite coarsely crystalline rock, and is an unusual type. It occurs intrusive in phyllites and schists on the summit of Red Mountain, ten miles south of Butte.

The second analysis is that of a rock fairly typical of the batholith contact at many localities. It is a dark gray granular rock, rather finer grained than the granite into which it can in some places be traced by insensible gradations. It is a very basic diorite which approaches a hornblende-gabbro. The hornblende is quite stringy and of uralitic appearance, pale green passing into deeper green and into colorless forms. Brown biotite is rare. Orthoclase is present in small amount and only in interstices between more idiomorphic plagioclase. The latter shows an extremely fine zonal structure and varies between labradorite and albite, and will perhaps in a majority of cases have an average composition corresponding to andesine. A very little quartz is also present, together with apatite and iron ore as accessories.

The rock grades into one consisting mainly of zonally built basic plagioclase in small idiomorphic crystals, equal in amount to that of the combined dark colored constituents, brown pleochroic biotite and hornblende derived from light colored pyroxene, remnants of which still remain.

For the purpose of determining what changes, if any, are accomplished in the ordinary weathering of the granite, an analysis of a coherent but quite friable rock has been made. The material, which is quite typical of that commonly seen in natural exposures, is rather lighter in color than the perfectly fresh rock and has a clayey odor when moist. The greenish plagioclase and pinkish feldspar has been bleached to a dull white or waxy

tint. In the still more altered rock, and in the sands formed by its crumbling down, the white minerals are stained by iron rust. In the rock analyzed the biotite is partly fresh and unaltered, but many of the grains are dull and lusterless, and others are altered to green chlorite; more rarely the cleavages are coated by iron rust. The hornblende shows the most alteration. Some of the grains are fresh, but most of them show masses of ocher, and are penetrated by films of it along cleavages and the grains all show more or less chlorite as the first stage of alteration. These changes all indicate simple hydration and oxidation of the rock, and should accordingly be revealed in the analysis. The following tables show (I) the average composition of the fresh rock, (II) the composition of the disintegrated material, (III) the percentage of each constituent lost, (IV) the percentage of each constituent gained.

Constituents	I		II		III	IV	Limit of possible error of analysis
Silica	64.03		65.14	+1.01		1.41	.3
Titanic oxide	.60		.59	—0.01			
Alumina	15.58		15.63	+0.05		0.32	
Ferric oxide	1.96		2.37	+0.51			.1
Ferrous oxide	2.83		2.13	—0.70			.15
Manganese oxide	.11		tr.	—0.11	100.	10.	
Lime	4.20		3.62	—0.58	14.09		.1
Magnesia	2.15		1.85	—0.30	14.23		.2
Potash	4.11		4.29	+0.13		4.04	.2
Soda	2.76		2.63	—0.13	9.51		.2
Moisture combined	.73	.96	.75	+0.02			
Moisture below 110°	.23		.37	+0.14			
Baryta	.07		.10	+0.03			
Strontia	.04		tr.	—0.04			
Phosphoric acid	.18		.16	—0.02			
	99.86		99.68				

The fresh rock contained a little Cl, 0.17 per cent., the disintegrated rock none. The fresh rock held 0.06 per cent. S (as pyrite), the altered rock 0.05 per cent. SO_3.

While the changes in the character of the rock are largely physical, and its degeneration, due to the rapid expansion and

contraction to which it is here subjected in the extremes of temperature that are so characteristic of the climate, and the chemical changes made possible because of the opportunity for moisture to penetrate the minute cracks thus formed, yet the chemical changes themselves, slight as they appear to be, aid this degeneration by swelling up as the molecules become oxidized and hydrated.

The analysis shows a remarkably small amount of chemical alteration. It is evident, also, that the process is not the normal one of "weathering," since silica is not lost. The presence of sulphides in the rock itself, the proximity of mineral veins, and the presence of sulphurous fumes in the atmosphere which would, of course, acidulate the rainfall, probably account for this abnormal nature of the weathering. Under such circumstances none of the constituents of the rock are constant, since they are all capable of passing into solution under such conditions. As, however, an increase of silica could not take place, this substance must either decrease in amount, or remain constant, and the analyses can be best compared by assuming it constant.

WALTER HARVEY WEED.

AN ATTEMPT TO FRAME A WORKING HYPOTHESIS OF THE CAUSE OF GLACIAL PERIODS ON AN ATMOSPHERIC BASIS.

(Continued)

III.

LOCALIZATION OF GLACIATION.

THE problem of localization is in some sense independent of the fundamental hypothesis offered in this paper, and the suggestions which follow may be accepted or rejected without carrying necessarily an approval or disapproval of the main hypothesis.

The remarkable distribution of the great ice-sheets.—The chief centers of the Pleistocene ice-sheet lay on the north-northeastern plains of North America, and on the northwestern quarter of Europe. On the northwestern Cordilleras there was also a notable center, though it does not appear to have equaled the others in rank.[1] The north-northeastern American centers are properly regarded as chief because the spread of the ice-sheets from them

[1] This statement is perhaps open to some question. It is quite certain from field observations that the glaciation of the Cordilleran plateau in the United States and in British Columbia as far north at least as 51° Lat. was much feebler than that of the Mississippi basin at corresponding latitudes and much lower present altitudes. It seems also clear that the ice of the north Cordilleras did not creep out upon the plains to an extent at all comparable to the spread of the Scandinavian ice-sheet upon the plains of Europe. Considered from these points of view, and they seem to be the important ones, the statement can scarcely be questioned seriously. The evidences of glaciation on the mountainous border facing the Pacific from 48° northward are, however, quite impressive. They find their climax perhaps in the 4000 or 5000 feet of glacial débris which Russell reports in the foothills of the St. Elias range. In view of this it may perhaps be insisted that the glaciation of this region was exceptionally concentrated on the Pacific border, because of the abrupt rise of the surface and the height of the mountains, and that the glacial discharge toward the Pacific was also exceptionally effective because the high gradient; so that, taking this intensification into account, the sum total of ice formation and ice action in this region may not have been so much inferior to that of the European area as the surface distribution might seem to imply.

was much more extensive than from the other centers, and because they were not aided essentially by mountainous points of origin, for neither the Labradorean nor the Keewatin centers appear to have been initiated by mountainous elevations. It was a development of glaciation on plains, or at most on plateaus. This fact renders the American ice-fields conspicuously chief among all that developed in Pleistocene times. The glaciation of Europe was centered upon mountains; and remnants of glaciation still linger on the mountain heights of most of the old glacial fields, giving ground for the belief that the local topographic features were there important factors. The glaciation of northwestern Europe would possibly have been rather scant if it had received no greater topographic aid than was afforded in the Keewatin field, but apparently it would not have been absent.

It has often been remarked that the Pleistocene glaciation was gathered about the north Atlantic, but it can scarcely be too much emphasized that the greatest of the glacial areas, and by far the most phenomenal, because of its plain topography, lies on the *western*, or what we are accustomed to regard as the *windward*, side of the Atlantic.

It is further to be noted, that on the western side of America, the glaciation, though notable, was still seemingly much inferior to that of the great northeastern plains; and this in spite of its mountainous character and its adjacency to the great Pacific Ocean, a topographic and hydrographic conjunction which expresses itself now in the most vigorous glaciation outside of the polar circles.

More or less nearly contemporaneous with the growth of the foregoing great ice-sheets, local glaciation developed on nearly all the mountain heights of the earth, whether in the northern or the southern hemisphere, and whether in high or low latitudes. This seems to imply an intensification of glacial conditions generally, but at the same time to indicate that the great ice-sheets were dependent on some special agency of localization. In saying that these scattered areas of glaciation were approximately

contemporaneous, no dogmatic assertion is intended relative to the exact contemporaneity of glaciation or to its alternation in the northern and southern hemispheres, nor respecting the doctrine of migration of glaciation in longitude. Observational data are yet insufficient to decide these questions. It is obvious, however, that the hypothesis under consideration postulates essential contemporaneity throughout the globe.

The constructive pole of the winds.—As a possible factor in the localization of glaciation, I venture to offer the suggestion that the axis of the earth's rotation and the axis of the atmosphere's circulation, constructively interpreted, are not identical. By the constructive axis of the winds I mean that ideal line about which the general currents of the atmosphere would be found to revolve if all minor movements were eliminated or equated and the aggregate east-west components only were regarded. In other words, it is suggested that the planetary system of circulation is obliquely adjusted to the planet. This was first suggested to me by a study of the peculiar courses of the arctic ice-drift. The polar ice-bearing currents are regarded by experienced arctic navigators as concrete expressions of the average movements of the atmosphere. To be sure, the ice-drift is affected by the ocean currents, but these are also, in the main, the results of the average direction and force of the winds, though they do not so immediately and definitely express it as the ice-drift, because they are also influenced by more remote agencies.

If the axis of the currently postulated "circumpolar whirl" of the atmosphere coincided with the axis of the earth, and if it were the poleward incurving spiral of the winds that swept the surface of the polar sea, the average ice-drift should assume, or tend to assume, a corresponding incurving spiral. The ice should crowd in toward the pole and rotate upon itself in a direction opposite to the hands of a watch. If this were true, the current which carried Nansen from east to west should have flowed from west to east.

If the axis of the "circumpolar whirl" coincided with the axis of the earth, and it were the *outward-running* spiral that

swept the surface of the sea, the ice-fields should rotate in the opposite direction with a centrifugal tendency which should carry the ice outwards and press it against the adjacent continents and give a voluminous discharge down the north Atlantic. An attempt to drift *toward* the pole in such a system would be an absurdity, and Nansen's feat would be inexplicable.

Observed ice-drift.—Neither of these are the phenomena observed. On the contrary, as now abundantly demonstrated, particularly by the remarkable drifts of the Jeannette and the Fram, the average movement near the coast of northern Asia and Europe is westward and slightly northward. This course is held until Greenland imposes itself as a barrier. The outer margin of the ice flow is then forced southward, but immediately it reaches Cape Farewell it curves closely about the point (at least during the summer months) and flows northward and westward to the vicinity of the arctic circle. It here encounters a new barrier in the islands of the American Arctic Archipelago and again moves southward.

On the north coast of Greenland, so far as known, the ice presses hard upon the land, as though its normal course were southward. It flows persistently into the channel between Greenland and Grinnell Land, and gives rise to that strenuous ice-pack which has again and again been assailed by arctic navigators with such great daring and such little success. The recent adverse experiences of the Windward and the Fram are but a renewed expression of the persistence of this south-southwestward drift of the ice currents.

On the north side of the Arctic Archipelago, west of Greenland, the ice crowds hard against the shore, and has thus far prevented the full penetration of Jones Sound or any of the other straits between the northern range of islands. The blocking of Jones Sound appears to be the result of an eastward as well as southerly crowding of the ice.

Farther to the west Banks Strait and McClintock Channel together form a continuous and rather broad water way, beginning in longitude 130° west and stretching southeasterly to

longitude 95° west. This channel is always tightly jammed with ice pressed in from the northwest. So persistent and strenuous is the pressure of this ice-pack that it constitutes an effectual barrier to the northwest passage, and has thus far mocked all attempt to force it. This implies a definite and persistent movement from the northwest to the southeast.

It appears, then, that from far east of Greenland to the western limits of the northern archipelago there is a definite convergence of the ice currents toward a point located somewhere north of Hudson Bay, *i. e.*, a point lying to the north of the two great centers of Pleistocene glaciation, the Labradorean and the Keewatin, and on a meridian that runs between them.

It is interesting to note that the point of convergence lies in the general vicinity of the magnetic pole, and this obviously leads to the further suggestion that there may be some genetic connection between the two as yet undetermined.

Concurrent in import with this is the fact that on the opposite side of the north pole the coasts of northern Asia and Europe become partially free of ice each season. This, although doubtless partly due to the effects of the fresh water borne in by the great rivers of those coasts, is probably none the less an expression of the fact that the polar ice is not crowded down upon those coasts; for if it were, its great mass would completely overwhelm the effects of even the great Siberian rivers. This phenomenon, taken in connection with the direct observations of the ice-drift made by De Long, Nansen, and others, leaves little room for doubt that the great polar ice-field drifts away from the Eurasian coast and crowds toward Hudson Bay. The meridian of 90° may be taken as rudely representing the axis of this converging ice-drift. It is interesting to note that this same meridian bisects the Mississippi valley and crosses the southern apex of the great American glacial field.

Distribution of arid zone.—Correlated with this remarkable phenomenon is an equally remarkable distribution of the great desert tracts of the eastern hemisphere. Commencing on the Atlantic coast of Africa between 10° and 30° north latitude, the

arid belt stretches north of east across Africa and Asia until in Mongolia it lies between 30° and 50° north latitude. That is to say, in this stretch of 70° or 80° in longitude it has advanced 20° in latitude. If now we select the meridian at 90° east, at or about which the desert area reaches its northern culmination, and follow this through the pole to a point 20° beyond on the meridian of 90° west, we are in the vicinity of the point towards which the arctic ice-drift seems to concentrate. And if we follow the same meridian southward we reach the point in the Mississippi valley where the ice-sheet had its southernmost extension. It is to be noted further that this last point coincides with the region where a large percentage of the cyclones which descend from the northwest curve about and take northeasterly courses.

If there were space here to enter into other particulars, additional coincidences of an apparently significant nature might be found. The inference drawn is that the axis of the main polar whirl, if indeed the polar movement can be called a whirl, is not coincident with the axis of the earth, but lies at some point southward from it in the vicinity of the meridian of 90° west longitude and 20° more or less distant from the pole.

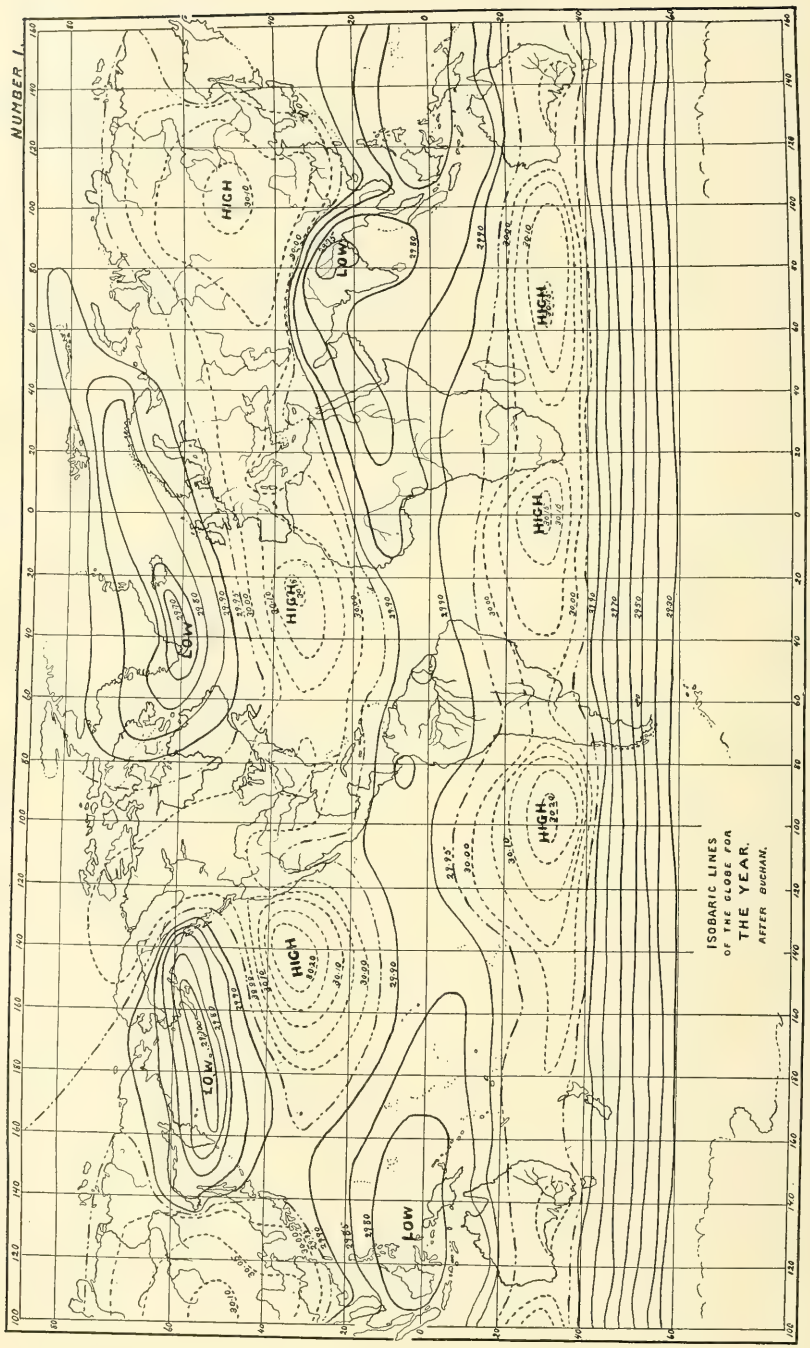
Indications of meteorological data.—As just implied, the idea entertained is not that there is a simple polar whirl whose axis is located here, but that the rather complex movements of the polar atmosphere, when combined and correlated, give a theoretical or constructive pole in this region. What is meant by this will appear more specifically from a study of the available meteorological data. Unfortunately these are yet quite imperfect and partially uncorrelated, and hence I have given precedence to the natural correlation expressed in the ice-drift. The International Circumpolar Commission has not yet combined and discussed its data. It may therefore be most convenient to have recourse to Buchan's[1] or Hann's[2] meterological maps for

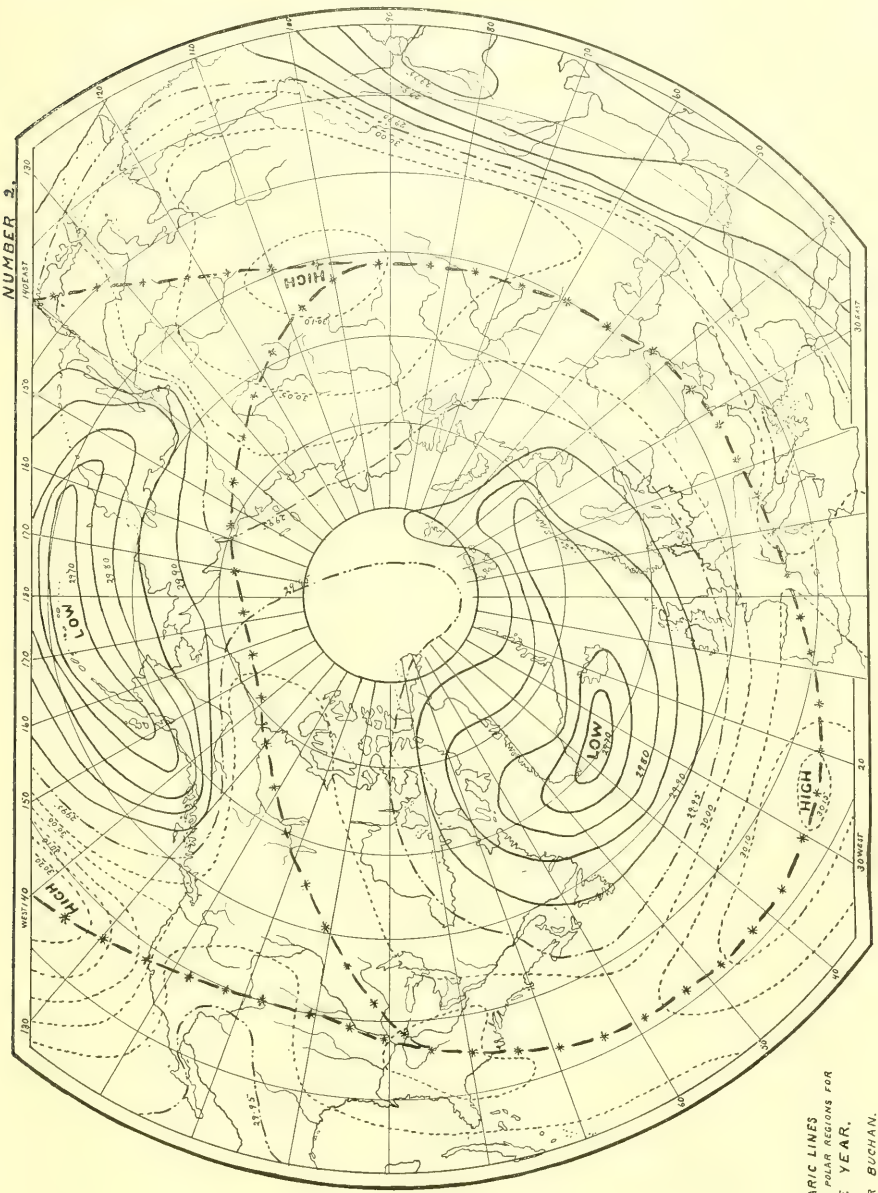
[1] Challenger Reports. Physics and Chemistry, Vol. II, Atmospheric Circulation. Maps 51 and 52. These include the main data gathered by the International Circumpolar Stations.

[2] Berghaus Physical Atlas.

the general features of atmospheric pressure and circulation. An inspection of Buchan's isobaric maps shows that there are, north of 45° north latitude, two nearly permanent areas of *low* barometer and one of *high* barometer. (See accompanying sketch maps 1 and 2, based mainly on Buchan's.) The area of high barometer is located in Asia on the meridian of 100° east longitude. It may perhaps be regarded as one of the normal high areas that theoretically belong to the parallel of 30° north latitude, but which has been displaced 20° to the northward by the topographic conditions of the great Eurasian continent. Its two chief companions under this view lie, the one in the east Atlantic centering near the Azores, about 30° north latitude and 25° west longitude, the other in the east Pacific, off the coast of California, in about 35° north latitude and 140° west longitude. But the Asiatic area of high pressure seems to combine in itself also the function of a polar center, for no other center, high or low, lies between it and the pole. Moreover, it is above mid-latitude, and is nearer the parallels of the two permanent areas of low pressure of the arctic region than to those of its 30° correlatives, for it lies itself in 50° north latitude, while the arctic "lows" lie in 55° and 60° north latitude respectively.

Furthermore, as shown on Buchan's map 52, these high-latitude centers are arranged about the pole at nearly equal distances from each other, the Asiatic "high" being in about 100° east longitude, the north Atlantic "low" in about 35° west longitude, and the north Pacific "low" in about 170° west longitude, *i. e.*, their successive distances from each other are 135°, 145°, and 140°. While these centers shift somewhat during the seasons, they are essentially fixed, the above statements being based on the isobaric averages for the year. These centers are therefore to be distinguished from the familiar moving cyclonic centers and are to be regarded as enduring factors which express the essentially permanent circulatory features of the circumpolar atmosphere. The Asiatic "high" is a permanent anti-cylonic area characterized by descending outward-flowing currents, attended by low precipitation and clear air. The north Atlantic


NUMBER I.
HIGH
LOW
HIGH
HIGH
HIGH
HIGH
LOW
LOW
LOW
HIGH
ISOBARIC LINES
OF THE GLOBE FOR
THE YEAR.
AFTER BUCHAN.



ISOBARIC LINES
OF THE NORTH POLAR REGIONS FOR
THE YEAR.
AFTER BUCHAN.

and north Pacific "lows" are permanent cyclonic areas with inflowing ascending currents attended by high precipitation and prevalent fogs.

Of the two "lows" that of the north Atlantic is the broader and more northerly, and appears to be the more influential factor now, as presumably it was in Pleistocene times. The north Atlantic "low," according to both Buchan and Hann, centers near the apex of Greenland; the north Pacific "low" centers on the Aleutian islands.

It is not difficult now to understand the peculiar behavior of the ice-drift of the polar seas. The Asiatic "high" with its outflowing currents pushes the ice off the Asiatic coast, while the currents inflowing toward the two "lows" impel it toward a point between the two. The Asiatic "high," however, develops more to the northeast of its center than to the northwest, and the North American area of moderately high barometer extends a tongue to the northwest between the two "lows," so that the two high areas approach each other north of the north Pacific "low" and reduce its influence upon the high latitude currents. These are therefore directed disproportionately toward the north Atlantic "low," and give to it a dominating influence. Buchan's maps of wind-directions for the winter months (when local influences are reduced to the minimum) show that the prevailing wind currents flow concentrically about the north Atlantic center from the Lena on the east to the MacKenzie on the west, a stretch of 220° longitude.

Correlation of circumpolar currents.—But in considering the circumpolar circulation as a whole, it is necessary to combine all the movements about all these centers to find the true dynamic center or the constructive pole of the winds. While such a combination cannot be accurately made from present data, it is obvious that it must place this constructive pole somewhere to the northward and westward of the north Atlantic "low" and nearer to it than to either of the other centers. The point toward which the ice-drift converges satisfies these conditions, and may be taken as nature's own practical correlation. Possibly

the magnetic pole may prove to be another expression of the same correlation, made indirectly through the agency of electric and magnetic dynamics springing from atmospheric circulation.

One-sided location of "lows."—As already noted, the two areas of permanent low barometric pressure are located on the American side of the globe and have their centers, according to Hann and Buchan, less than 140° Long. ($\frac{7}{18}$ of the total 360°) apart. They are notably elongated in a general east-westerly direction, the north Atlantic area being especially extended easterly and northeasterly, and somewhat curved and reniform. If the isobaric line of 29.95 inches, which represents the average pressure for the globe, be taken as defining the low areas, their borders are only about 40° Long. apart on the American side, while they are 115° Long. apart on the Asiatic side in about the same latitude. In other words, the distance between the borders of the low areas on the American side is about one third of the distance on the Asiatic side. The distance between the borders of the "lows" is only about one half their own longitudinal diameters. The tract between the borders of the "lows" on the American side being thus relatively narrow, it might naturally be anticipated that the currents within it would be much influenced by those of the adjacent depressions, and this seems to be in a large measure realized, for the winds on the northern American plains east of the Rocky Mountains flow in the main concentric to the north Atlantic depression. On Buchan's map 52, which has a polar projection, the isobaric line of 30 inches describes nearly a circle about a point not far from the center of Greenland's ice-field. (See sketch map 2.) In a rude way the prevailing winds within this circle and for some short distance without it whirl about the Greenland center with inward tendency. The influence of the north Pacific depression does not appear to be appreciably felt east of the mountains.

Relation of moving cyclones.—It is interesting to note in this connection that many of the moving cyclones that traverse the mid-latitudes of our continent seem to take their origin in the tract between these two permanent cyclonic areas, or in the

region immediately to the south of it, and that possibly they are but secondary eddies generated by the action of the great fixed ones. As before noted, the migrant eddies swing concentrically about the north Atlantic depression.

Location of present glaciation.—Coming closer home to the glacial problem, it is important to note that the two great areas of present arctic glaciation are intimately related to these two permanent cyclonic areas. The Alaskan and Greenland ice-fields not only lie within these areas of barometric depression, but are peculiarly related to them. It is, at first thought, not a little singular that, while the Alaskan ice-fields lie on the *northeast* border of the Pacific "low," the ice-fields of Greenland lie in the *northwest* quarter of the north Atlantic "low;" that is, the chief glaciations lie *between* the centers of the two permanent cyclonic areas. The apparent anomaly of maximum ice accumulation in the northwest quarter of the Greenland "low" probably finds its explanation in the following considerations:

1. The maximum precipitation (which is normally found in the southeast quarter of a "low") and the maximum ice accumulation should not theoretically be coincident; for the ice accumulation is not a true measure of the precipitation, but merely a measure of that *part* of precipitation which is frozen when it falls and survives melting and evaporation. Now in the north and west quarters a larger percentage of the precipitation is snow than in the south and east quarters, where the sum total of precipitation is greater. Moreover, the melting in the north and west quarters is obviously less than in the opposite quarters. The annual isotherms for the southeast quarter range from 35° up to 50° F., while those of the northwest quarter range from 35° down to 0° F. The ice-fields of Greenland and the lands west of it lie in the tract whose annual average is below 32° F. Iceland, whose precipitation is greater, but whose glaciation is less, lies between isothermals 35° to 40° F.

2. The configuration of the water area which wraps about Greenland gives special snow-precipitating efficiency to the winds that swing about the depression on its north side and

cross Greenland from the east and northeast. *The nature of the circulation is such that Greenland is really on the leeward side of the north Atlantic.* This is shown by the following tables of prevailing winds. The first is from the prolonged observations recorded at Godthaab and Upernivik, by Dr. Rink; the second, from those taken under the direction of General Greeley at Fort Conger in the years 1882 and 1883:

PERCENTAGES OF TIME DURING WHICH GREENLAND WINDS BLOW FROM THE DIRECTIONS NAMED

	At Upernivik Lat. 72° 47′. Long. 55° 35′				At Godthaab Lat. 64° 11′. Long. 51° 43′			
Direction	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
N.	25.5	33.9	31.9	28.8	33.1	37.4	30.3	25.5
E.	34.3	23.1	16.2	36.5	38.4	24.8	8.6	33.6
S.	15.5	20.3	28.0	18.1	16.1	21.7	32.9	22.9
W.	1.8	2.5	6.4	4.4	4.9	5.7	15.1	6.2
Calms	22.9	20.2	17.5	12.2	7.5	10.4	13.1	11.8
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

FREQUENCY AND VELOCITY OF WINDS AT FORT CONGER, LAT. 80° 44′ N., LONG. 64° 45′ W.

Direction	1881-2		1882-3	
	Times	Miles	Times	Miles
N.	393½	1522	420	2401
N. E.	761	3061	1022	4613
E.	1151½	4843	1369	4061
S. E.	678½	3605½	862	3650
S.	683½	3864½	775	4214
S. W.	678	2011	900	3059
W.	371	949	343	997
N. W.	296	731	387	1142
Calm	3408	1282	2682	50

The winds of the summer months are much influenced by local features, especially by the sea, the naked earth and the ice fields, respectively, while in the cold months a nearly uniform mantle of snow or ice covers the whole surface in common, and removes essentially all sources of variation except those of

relief. Including the data of the summer months, the preponderant direction is shown by the above tables to be easterly. Omitting them, it becomes northeasterly. But in either case the dominant winds come from the north Atlantic, and justify the statement that Greenland is on the leeward side of the high north Atlantic and the adjacent part of the Arctic Ocean.

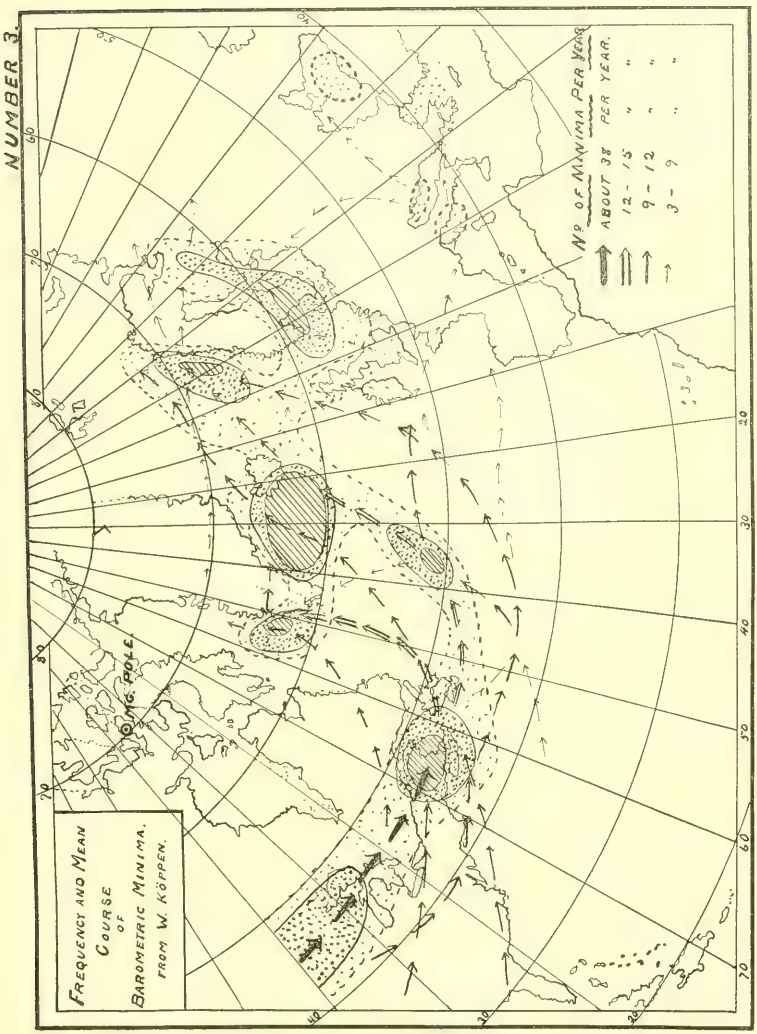
In the eastern part of the Arctic Archipelago as far south as Hudson Straits the winds are very variable, a fact quite consistent with their physiographic surroundings, and with their location well toward the interior of the north Atlantic depression.[1]

The paths of the moving cyclones.— Besides the general fact that the prevailing atmospheric currents from the Mackenzie to the Lena form a great eddy, with maximum conditions of glaciation on the north and west of its chief center near the apex of Greenland, it is to be noted that the paths of the moving "lows" are greatly influenced by the permanent depression at the center of the eddy. This is graphically shown for the north Atlantic portion of the region by Hann's map No. 36[2] herewith reproduced (sketch map 3), in which it is shown that nearly all the moving "lows" curve to the northward in courses more or less rudely spiral or concentric to the permanent "low." The larger number of paths run spirally in toward the permanent center, which suggests the conception that the great fixed cyclone is in some sense an aggregate of numerous small in-running migrant cyclones. If data were sufficient to permit the following of the complete courses of all the migrant cyclones from their origin to their extinction, a dominant system of great interest would probably be shown. As already remarked, a considerable number of these migrant cyclones originate in the American northwest.[3] These show a notable habit of sweeping southeasterly

[1] I am greatly indebted to the Hon. Willis L. Moore, Chief of the United States Weather Bureau, and to Professor R. F. Stupart, of the Canadian Meteorological Service for transcripts of data relative to various high latitude stations not otherwise at my command.

[2] Berghaus' Physical Atlas.

[3] "The North American continent is the region where cyclones form in large numbers, and Europe and Asia the region where they dissipate." F. H. BIGELOW: Am. Jour. Sci., Vol. VIII, December 1, 1889, p. 443.


NUMBER 3.
FREQUENCY AND MEAN COURSE OF BAROMETRIC MINIMA. FROM W. KÖPPEN.
N. MAG. POLE
Nº OF MINIMA PER YEAR
ABOUT 38 PER YEAR.
12 - 15 " "
9 - 12 " "
3 - 9 " "
BY J. HANN.

into the Mississippi Valley, where they curve about and follow the courses shown on Hann's chart. These courses seem to fall into two classes, the one running spirally inward toward the center of the great fixed eddy, the other spirally outward with dispersive tendencies. A suggestion relative to the possible reason for this last feature will be given in another connection.

A more general view.—While all generalizations now entertained must be held very tentatively, because of the imperfection of present data, a general conception of the circulation of the northern part of the northern hemisphere, which will serve to bring together and give coherence and unity to the more special features which have been discussed, may be pardoned.

The whole temperate and polar region is divisible into areas of high pressure (annual average above 29.95 inches, 760 mm) in which the dominant currents are downward and outward, and areas of low pressure (annual average below 29.95 inches, 760 mm) in which the dominant currents are inward and upward. The mutual disposal of these gives a basis for a general view of the atmospheric circulation.

The high pressure loop.—In tracing the former we may start, for convenience, on the 30° latitude tract at its Atlantic node near the Azores, where it lies between 30° and 40° north latitude. Tracing it thence easterly, it inclines notably to the north, and at the meridian of 100° east, has made a northerly gain of 20° latitude. Thence onward it continues to gain in latitude, at first more rapidly and then less rapidly to about the meridian of 180°, when its course is nearly normal to the meridian, and its latitude may be roughly taken as 75°. Thence onward its course is south of east to the Mackenzie basin, and thence more southerly over the Canadian plains east of the Rocky Mountains until it again joins the high tract that normally lies near 30° latitude. It thus makes a great loop swinging around the pole, and passing near it at its climax in latitude, and enclosing the great north Atlantic eddy (see sketch map 2). The tract is accentuated by nodes of an anticyclonic nature. The chief of these is the great "high" of Asia. This protrudes to the

southeast, and is constructively connected in that direction with the 30° belt, which develops a strong anticyclonic node near the California coast, beyond which it connects with the main tract which crosses the United States and the Atlantic near its normal position. Between this connection across the Pacific and the main loop before traced lies the Aleutian depression.

The high tracts of the northern hemisphere therefore form (1) a great loop embracing the great north Atlantic depression and, (2) incidentally, as it were, a minor loop embracing the north Pacific depression. The great loop is not conceived as a current, much less a whirl, but as a tract along which the upper atmosphere habitually descends with outflowing tendencies. The enclosed area of low pressure is a tract over which the lower atmosphere habitually ascends with inflowing tendencies.

Now the main loop and the main enclosed eddy lie on one side of the northern hemisphere and embrace the chief area of Pleistocene glaciation. This main loop and its enclosed eddy embrace about three fourths of the hemisphere north of 30° N. Lat. In the area left vacant, so to speak, the secondary Aleutian eddy is developed and covers the main area of the Cordilleran Pleistocene glaciation.

There can be no question that this peculiar configuration is due to physiographic influences, particularly the oblique attitude and peculiar oceanic circulation of the Atlantic, and the similar obliquity of the main body of the eastern continent. To realize the full force of this obliquity one should trace on a globe the great axis of the eastern continent from Cape Verde on the protruding portion of Africa to Cape East at the extremity of Asia, an immense spiral, and then, starting from the coast of South America near the lesser Antilles, trace the axis of the North Atlantic to the heart of the Polar sea in a similar great spiral, essentially parallel to the former. With these primary influences many secondary ones are joined, some acting concordantly to intensify the obliquity of the circulation, and others acting discordantly and tending to destroy its symmetry, and modify its configuration.

This discussion of the present circulation, too protracted for this place, yet too brief for its purpose, has seemed necessary to make clear the conception entertained respecting the agencies of localization. It has previously been urged in this paper that a reduction of the carbonic acid in the atmosphere and the consequent reduction of its heat-absorbing capacity must intensify the influence of all surface features. In the discussion of existing glaciation I have endeavored to connect the present great ice-fields genetically with the two great areas of low pressure, and to associate them with an oblique disposal of the great circulatory features. The chief centers of present glaciation lie on the borders of the American continent. The chief Pleistocene glaciations, were concentrically arranged about these centers. As has been pointed out by other students of Pleistocene glaciation, the great northeasterly ice-sheet had its western, southern and southeastern limits almost coterminous with the predominant paths of northern migrant cyclones. To complete the hypothesis of localization it is therefore only necessary to assume an intensification of the present oblique system of circulation, with a further shifting of the centers of depression in the direction of the present displacement, accompanied by a sufficient depression of temperature. And these are the effects assigned to a reduction of the atmosphere's thermal capacity due to loss of carbonic acid.

Suggestion relative to migrant cyclones.—One further feature deserves notice. If the constructive pole of the winds lies somewhere between the earth's pole and the American continent, the frictional action of the earth will affect the two sides of the eddy in opposite senses. On the western side (from the American point of view) the friction will tend to drag the bottom air toward the cyclonic center and crowd the isobars upon each other. As the lines of the wind circulation and the earth rotation cross each other obliquely, a predisposition to form gyratory or cyclonic eddies may be inferred, and this may be one of the sources of migrant cyclones which may be regarded as small eddies in the grander cyclonic movements.

On the eastern side of the pole of the winds, the earth movement tends to drag the bottom air away from the center and this is perhaps one of the reasons why the moving cyclones on that side show a tendency to dispersal, both in course and in force, as previously noted.

Possible relation to terrestrial magnetism.— It is scarcely appropriate to this paper, if it were in my power, to discuss the relations of this oblique system of atmospheric circulation to the oblique system of terrestrial magnetism. Crudely stated, the notion entertained is that an atmosphere charged with electricity, circulating obliquely about a rotating earth which is inset with magnetic and magnetizable matter, might give rise to a magnetic system which should express the dynamic resultant of the atmospheric circulation. A comparison of the magnetic and atmospheric charts shows so many points of resemblance, some of which are striking *peculiarities*, as perhaps to justify this tentative notion until the mystery of the earth's magnetism be solved. Connected with terrestrial magnetism are auroral manifestations whose distribution is notably similar to that of the chief Pleistocene glaciation, as was remarked many years ago when first the progress of exploration outlined the extent of the glacial deposits. It can hardly be presumed that either terrestrial magnetism or auroral displays have in themselves any causal connection with glaciation, but if they are dependencies of atmospheric circulation they become eminently serviceable to glacial students by affording a tangible concrete expression of the dynamic correlation of the atmospheric circulation, free from the intricate complexities of the latter; in short, a natural resultant at easy command. The verity of the notion must, of course, depend wholly on the outcome of magnetic investigations on their own lines, which happily are now being vigorously prosecuted.

SUGGESTIONS RELATIVE TO MINOR GLACIAL OSCILLATIONS

It has already been noted that besides the oscillations of epochal order there were subsidiary ones which left their record in a series of concentric moraines which corrugate the individual

sheets of glacial débris. The latest drift sheets show this best. That designated Wisconsin is accentuated by nearly a score of peripheral ridges. In a recent admirable paper by Keilhack[1] it is shown that similar lines of halt, and perhaps of minor advance, mark the corresponding European glacial sheet as deployed on the plains of north Germany; indeed, even in some of the greater details, a striking correspondence is traceable between the two series, whose general identity in age and kind were long since noted by Salisbury.[2] These minor oscillatory phenomena seem, therefore, sufficiently general and sufficiently important to require an explanation, and this explanation is not necessarily connected with the fundamental cause of glaciation. The preceding discussion carries in itself a suggestion which is worthy of note in passing. If the localization of the great ice-sheets was dependent on the general circulation of the atmosphere, any periodic shifting of the circulation of moderate magnitude might be competent to cause a shifting of the ice-sheets of corresponding nature. There are historical facts that give some color to the notion that such shiftings have taken place within the period of human records. The oscillations of existing glaciers point in a similar direction. There is clearly a secular shifting of terrestrial magnetism, but the nature of its cycle is yet undetermined. Current opinion gives it a periodicity which would quite well satisfy the demands of the concentric moraines.

GLACIATION NEAR THE CLOSE OF THE PALEOZOIC ERA

While the occurrence of extensive glaciation in India, Australia and South Africa near the close of the Paleozoic era may be regarded as fully established, a specific discussion of its origin along the lines of an atmospheric hypothesis presents formidable difficulties, because the exact date of the glaciation, its

[1] Die Stillstandslagen des letzten Inlandeises und die hydrographische Entwickelung des pommerschen Küstengebietes. Separatabdruck aus dem Jahrbuch der königl. preuss. geologischen Landesanstalt für 1898. Berlin.

[2] Terminal Moraines in North Germany. Am. Jour. Sci., Vol. XXXV, p. 401. Series 3.

immediate antecedents and the nature of contemporaneous conditions in other parts of the world are not yet satisfactorily determined. No embarrassment attends a merely general application of the atmospheric hypothesis set forth in this paper, and perhaps it would be wise in the present state of knowledge to be content with such general application. But the main purpose of the paper — to develop a *working* hypothesis, helpful in the promotion of investigation — would be measurably defeated thereby, for a general theory merely supposed to be applicable in some indefinite way, not even specifically thought out, much less shaped to promote definite inquiry, falls short of working qualities. Were the Paleozoic glaciation a high-latitude phenomenon which could be referred to the same category as the Pleistocene glaciation, we might well leave specific discussion until further data were afforded, for few additional doubts as to the verity of the hypothesis and probably few new lines of inquiry would be raised. But the Paleozoic glaciation presents characters so extraordinary as to render it the supreme problem of glaciation. In it every hypothesis finds its severest test. No hypothesis that does not, in some remote way at least, approach an elucidation of this supreme case can have serious claims to acceptance as a working theory. It is, therefore, imperative to frankly and fully recognize this crucial problem and deal with its difficulties as well as existing data permit. A really satisfactory discussion is quite impossible in the present nature of the case. The attendant atmospheric and geographic conditions must be postulated, consciously or unconsciously, but the data for such postulates are imperfect and their interpretation is at best not more than probable. It is hoped, however, that fairly good reasons can be assigned for everything assumed in this paper.

The essential facts that make the Paleozoic glaciation a peculiarly strenuous problem are these :

1. It occurred in an early stage of the earth's history. No appeal can, therefore, be made to an advanced state of secular cooling leading on the "final winter" nor to any senile condition

inherent in an aged earth. If the traditional view that the primitive atmosphere constituted a vast store that has been gradually drawn upon throughout the ages in the formation of the coals and carbonates, and was their chief source, the atmosphere at the close of the Paleozoic era must still have been rich, deep and dense to a degree far surpassing the present atmospheric state, for vast deposits of coal and carbonates have since been made through its agency. One of the most conservative as well as most competent estimates of the consumption of carbonic acid since the Paleozoic era places it at 5000 times the present content. To be conservative, let this be halved and halved again, and still the content of carbonic acid is 1250 times that of the present. This atmosphere was so different from that of the Pleistocene and present period as to render uncertain, if not inapplicable, all arguments founded upon the phenomena of the latter. The question of the constitution of the Paleozoic atmosphere is, therefore, fundamental, because it affects the substratum of all arguments based on present or recent experience. Even with the above excessively reduced estimate, do we reach an atmospheric environment in which any known agency applicable to the case can be reasonably postulated as competent to cause general glaciation? In such an atmosphere, or in any atmosphere greatly richer than the present in heat-absorbing and heat-retaining qualities, are there any sufficient grounds for seriously supposing that any of the putative causes of Pleistocene glaciation, whether topographic, geographic, latitudinal or astronomical, could produce such a glaciation as is recorded under the tropics of the far Orient. It is not a part of the purpose or the method of this paper to antagonize other hypotheses, but rather to invite their development into working coöperation and competition with that herewith advanced; but a wholesome interaction of hypotheses will be best attained by eliminating wholly untenable grounds and by bringing all hypotheses within the limital conditions of competency. It is, therefore, no transgression of my purpose to urge the question whether all hypotheses are not required, for their own conservation, to accept so much of the

fundamental postulates of the atmospheric hypothesis as are needful to give an atmosphere compatible with glaciation under such other conditions as prevailed in India, Australia and South Africa in the later Paleozoic.

2. The localization was most extraordinary. The chief areas lay under the tropics — the Indian, under the Tropic of Cancer and the Australian and South African, under the Tropic of Capricorn. The Indian area stretched southward to 17° 20′ N. Lat. and northward to the vicinity of 35°. The Australian area stretched north to 20° 30′ S. Lat. and southward (in Tasmania) to 42°. The extent of the South African area is less well known, but centers about 30° S. Lat. It appears then that on both sides of the equator glaciation reached two or three degrees within the tropics, while in the opposite direction general glaciation has not been traced beyond 42° To the south this signifies little because of the prevalence of the sea. To the north the apparent limitation is very singular and doubtless very significant. It cannot, however, be positively asserted that glaciation did not prevail in the higher latitudes, but no decisive evidence of it has yet been discovered. At the same time it must be recognized that many evidences of remarkable transportation and of unusual bowlder accumulation, and indeed of occasional striation have been reported, and that these have been attributed to glacial agencies by geologists of high standing. It cannot be affirmed at present that these phenomena were precisely contemporaneous with the glacial deposits of the oriental tropics, but they were nearly so.

In the southern portion of Brazil there are deposits strikingly similar to the glacial beds of Africa and Australia, but no striation or distinctive marks of glaciation have yet been authoritatively reported.

The southernmost extent of the lowland Pleistocene glaciation was about 37° N. Lat. The Paleozoic glaciation, therefore, reached 20° farther.

The altitude of the glaciation.—Respecting the altitude at which the Paleozoic glaciation took place, it is to be remarked

that in some cases there is so intimate an association with marine deposits as to indicate that the ice reached the sea level and discharged icebergs. The associated marine fossils do not seem susceptible of explanation by mechanical admixture through the action of the ice, because of their condition and their position in the embracing sediments. Oldham[1] reports that certain bowlder-bearing mudstones "contain delicate Fenestellæ and bivalve shells, with the valves still united, showing that they had lived, died, and been tranquilly preserved where they are now found, and proving, as conclusively as the matrix in which they are preserved, that they could never have been exposed to any currents of sufficient force and rapidity to transport the blocks now found lying side by side with them. These included fragments of rock are of all sizes from a few inches to several feet in diameter."

These and other evidences leave little room to doubt that a part of the glaciation at least affected low horizons. On the other hand, most of the glacial beds are so related to their own glaciated floor as to show that they were formed by land ice. This is confirmed by the nature of the striæ, the relations of the transported blocks to their source, and the association of the glacial beds with fresh-water deposits. At present some of the glacial beds are 3000 to 3500 feet above sea level (Tasmania), but in general they are much lower. How much of this altitude is due to subsequent changes I do not know. There is, however, much evidence that the glaciation was not of the alpine type, or at least not simply of the alpine type. It spread over broad areas of moderate slope.

In kind of glaciation and in topographic relations the Paleozoic phenomena seem to have been of the same class as the Pleistocene.

Approximate age.—Professor David and other cautious writers of recent date do not attempt to locate the horizon of this glaciation nearer than Permo-Carboniferous. It is certain that in the Salt Range in northwestern India a Productus fauna overlies the

[1] R. D. Oldham: Rec. Geol. Surv. India, XIX, 1886.

bowlder beds. From this and other paleontological evidence it would seem that the lowest of the glacial deposits at least antedated the disappearance of the Permian faunas from the seas.[1] It is unfortunate that the peculiar nature of the formation, and the not less peculiar nature of the associated flora, make it impossible at present to fix its exact horizon in terms of the European and American standards, so that the contemporaneous conditions in these regions could be determined. However, for the application of the atmospheric hypothesis the foremost question is the relationship of glaciation to the great agencies that affected the constitution of the atmosphere. These agencies were (1) the formation of coal, and (2) chemical reaction between the air and the earth's surface.

1. Relative to the first, it is certain that the glaciation closely followed the great coal-depositing period, and indeed fell in with the latest stages. In Australia there are considerable deposits of coal (the Gretna Coal Measures, embracing twenty to forty feet of coal) deposited "between the erratic-bearing horizon of the lower marine series and the similar horizon of the upper marine series" (David).[2] If, therefore, we look to the deposition of coal as the agency of atmospheric exhaustion, the relationship is nearly ideal.

2. If we look to elevation, and consequent large earth-contact, the relationship does not appear to be what theory would demand. It can scarcely be questioned that at the close of the Paleozoic period there was a very unusual surface movement, affecting great areas of the earth's surface and increasing largely the exposure of the land. The period appears to have been altogether comparable to that at the close of the Tertiary period. If we were seeking the cause of the glaciation assigned to the Triassic, or the occasion of the salt and gypsum deposits

[1] There is some evidence of another glacial horizon at or about the base of the Triassic (well indicated in White's excellent synopsis, Am. Geol., May 1889, table, p. 315). The present discussion will, however, be confined to the lower horizon, that of the Talchirs and their equivalents.

[2] Quarterly Jour. Geol. Soc., Vol. LII, May 1896, p. 300.

so widely prevalent in the Permian and Triassic formations, this elevatory movement would stand in the proper relations. But, if present evidence is to be trusted, it does not stand in the proper antecedent relations to the Permo-Carboniferous glaciation, at least not as the primary agency. Still, though there is an absence of evidence of large exposure of the land surface to atmospheric degradation for a notable period preceding the Permo-Carboniferous glaciation, there are good grounds for believing that the great era-closing movement of the Paleozoic had made notable advance even at this time.

The Gondwána elevation.—The glacial beds under consideration form the basal members of the remarkable Gondwána series, the chief members of which are land and fresh-water deposits. These in themselves imply a recently rejuvenated topography, for an ancient topography has a perfected drainage system and adjusted gradients. It is the dominant belief of those who have most studied the region circumjacent to the Indian Ocean, that the formation of the Gondwána series and the development and distribution of the remarkable Glossopteris flora, imply extensions and connections of land of a somewhat unusual kind. If this belief were accepted to the full extent urged by its strongest advocates, it would in itself involve a very large exposure. I am not disposed, however, to force the doctrine of a Gondwána continent beyond the most modest limits, however much it might contribute to a favorable reception of the hypothesis under discussion. It appears to me that the distribution of the Glossopteris flora may be in some notable part a climatic rather than a topographic effect; that is to say, the peculiar atmospheric conditions, of which glaciation was the supreme expression, distinguished that quarter of the globe from the rest, and may in themselves have controlled the distribution of the peculiar flora in question. It may therefore only be necessary to postulate such an extension of the land as was required to permit the migration of the flora and its companion fauna.

However this may be, it is very generally agreed that some notable land extension prevailed as early as the origination and

distribution of the Glossopteris flora. It will be quite conservative to assume that this involved a land connection between India and Australia, and probably New Zealand, the connection presumably lying along the submerged platform which even to this day stretches southeasterly from Asia to the islands in question with slight interruptions. It is not improbable that between India and South Africa at least a partial bridge was formed by the elevation of the submerged plateau on which Madagascar and the Seychelles rest, together with the tract now accentuated by the Maldive islands.

A connection with South America (where the Glossopteris flora also appeared — southern Brazil and Argentina) involving the least radical departure from modern configuration, may have been made via New Zealand and the Antarctic continent. This, I believe, also best satisfies the general tenor of paleontological evidence.

If the geographic changes were confined to such connections and extensions of land as these, and to such moderate elevations as the nature of the glacial beds and the associated deposits seem to imply, and to such changes in the northern hemisphere as can fairly be assigned to the Permo-Carboniferous period, there does not seem to be adequate ground for attributing a very exceptional depletion of the atmosphere to land-contact alone, or chiefly, though it may have made some notable contribution in that direction.

Effects of atmospheric depletion by coal deposition.—We therefore turn to coal-formation as the effective alternative. There are no reliable estimates of the total carbon in the coal and carbonaceous deposits of the Carboniferous period, but such approximations as have been made seem to show that it equals several times the present atmospheric content, and that its extraction superadded to the increasing formation of carbonates resulting from the rising land would have been competent to reduce to the point of glaciation an atmosphere three or four times as rich in carbon dioxide as the present; in other words, such an atmosphere as the sub-Carboniferous climate seems to imply.

A question of no small interest is the special kind of effect which an atmosphere reduced by coal formation would induce as distinguished from that induced by depletion through earth-contact. In the latter, as already set forth, bicarbonates were the chief product, and carbon dioxide, temporarily locked up, played a very important part. Through the peculiar agency of the ocean this "loose" carbon dioxide hastened the development of glaciation, prepared the conditions for strong reaction and accelerated the reaction when inaugurated. In the formation of coal and like products no such effective temporary factor is produced. The carbon is, to be sure, temporarily held in the vegetation, but so much as decays goes directly back into the atmosphere, in the main, and the rest becomes permanently fixed. Neither part goes into an intermediate state of reserve, subject to being called forth by change of conditions as in the case of the second equivalent of the bicarbonates of the ocean. The action is somewhat analagous to the original carbonation of the silicates of the crystalline rocks in which the first equivalent of carbon dioxide when once united remains fixed (barring accidents to which coal is also liable), but in this case there is also a second equivalent of carbon dioxide temporarily locked up so long as a state of solution is maintained. Succinctly stated, without the unessential qualifications: (1) Depletion by coal formation is accompanied by no intensifying and reactive factor; (2) Depletion by conversion of silicates into carbonates is accompanied by an intensifying and reactive factor; (3) Depletion by the solution of limestone is wholly temporary in nature and specially capable of promoting intensification and reaction.

If, therefore, the impoverishment of the atmosphere as the prerequisite of glaciation in Permo-Carboniferous times was due, in the main, to the extraction of carbon in the form of coal and like deposits, there was absent, to that extent, the factor to which the hastening of glaciation and of reaction is assigned. Before glaciation could be affected in the measurable absence of this accelerating agent, it was necessary for the permanent depletion to go to greater lengths. Moreover the depletion when once

affected was essentially a non-reactive one. Of course the reactive factor was never really absent, for the formation and solution of carbonates was always in progress. In this case it is merely supposed to be the minor rather than the major factor. It is inferred, therefore, that a higher stage of permanent depletion of the atmosphere was reached before glaciation ensued through coal formation than would have been the case had the glaciation been produced by the formation of carbonates. To this, in a measure at least, is attributed the conditions which made it possible for the glaciation to affect lower latitudes in Permo-Carboniferous times than they did in Pleistocene times. As before noted, the Permo-Carboniferous glaciation extended 20° nearer to the equator than the Pleistocene.

The localization of the Permo-Carboniferous glaciation.—It remains to consider the remarkable localization of this ancient glaciation. The general principles involved are assumed to have been the same as those already applied to the Pleistocene problem, but the geographic factors were quite different, and it is here that the lack of complete data is most keenly felt. In Pleistocene times, as also at present, certain great geographical features are thought to have given a pronouncedly oblique circulation to the air currents of the northern hemisphere. In the southern hemisphere at present a much greater approach to symmetrical circulation prevails because great oblique features are absent. It is postulated that the configuration of Permo-Carboniferous lands and oceans was such as to seriously disturb the symmetry of the atmospheric and oceanic circulation of that hemisphere, and to give it peculiar form and special intensity.

The geographic features of the Permo-Carboniferous period.—The assigned changes introduced by the development of Gondwána land have been mentioned. These are thought to have prolonged the Asiatic continent southeasterly to Australia, and probably to New Zealand, and perhaps to the Antarctic land. This prolongation, taken with its backward projection across Asia and Europe, constituted an oblique feature of great extension. It also interposed a barrier which very notably modified

the water connections of the Pacific and Indian oceans. The warm equatorial currents which now flow through the numerous straits of the East Indies and add warmth to the Indian Ocean were turned back, and their heat retained in the Pacific. At the same time the cold currents of the southern Indian and the adjacent Antarctic oceans were shut out measurably or wholly from the Pacific, and turned northward into the equatorial portion of the Indian Ocean. There was thus a concentration of heat in the one and of cold in the other. If the suggested connection of New Zealand with the Antarctic continent was made, these cold southern waters would have been effectively shut out from the Pacific and forced to circulate through the Indian Ocean. If the other conservative changes suggested to meet the demands of the Gondwána phenomena were realities, the Indian Ocean took the form of a great triangle with a very broad base in the antarctic regions, and a narrowed apex reaching across the equator to the vicinity of the Indian glaciation.

In the north Atlantic region there is evidence that the great readjustment which closed the Paleozoic era had made notable advances at the probable time of the Oriental glaciation The New Red Sandstone of western Europe is not unlike the Gondwána series in general characters, and indicates a like rejuvenated land. Within it also are found arkose, conglomerates and breccias, often formed of large, far-transported blocks. "Some of these blocks are three feet in diameter, and show distinct striation. These Permian drift beds, according to Ramsay, cannot be distinguished by any essential character from modern glacial drifts, and he has no doubt that they were ice-borne, and, consequently, that there was a glacial period during the accumulation of the Lower Permian deposits of the center of England."[1] There is good ground to believe that previous to the formation of these deposits the land on the European border of the Atlantic had risen relatively. There are similar evidences on the American side. The close relations between the land faunas and floras on the two continents strongly imply a free

[1] Sir Archibald Geikie: Text-Book of Geology, p. 753.

land connection. This is most pointedly indicated by the distribution of the amphibians of the Carboniferous and Permian periods. The Branchiosauria, Aistopoda, Microsauria, and Labyrinthodontia vera were all represented on both continents, and unless the doctrine of parallel evolution be pushed to a seeming extreme, the only satisfactory explanation is an ample land connection. The amphibians of today are fatally affected by salt water, and even their eggs lose their vitality after a short submergence in it. It cannot be positively affirmed that this was true of the Carboniferous amphibians, but the presumptions appear to lie in that line. At any rate the occurrence of all the leading branches on both continents renders it quite improbable that a broad ocean intervened. It is therefore assumed that the Atlantic Ocean was restricted at the north by such connection. To be definite, it is assumed that it essentially terminated south of the Greenland-Iceland-Faroe platform, or possibly south of the Telegraphic plateau.

There are few data that give specific indications as to the configuration of the north border of the Pacific at this time, but the considerations that have just been urged with reference to the distribution of the fauna and flora are apparently best satisfied by supposing an emergence of the very slightly submerged continental platform of the arctic region generally. This is in harmony with the history of the preceding Paleozoic periods during which the Eurasian and North American continents were essentially a unit and free migration from one to the other was an oft-repeated, if not predominant, phenomenon. If this be the true inference the Pacific Ocean was limited at the north to about 60° Lat.

In equatorial latitudes it is not improbable that the Atlantic and Pacific oceans were united between the main bodies of the North American and South American continents, so that a commingling of waters took place here not unlike that which now obtains between the Pacific and Indian oceans.

It is not improbable also, judging from the distribution of Permian marine beds, that inland seas extended along the

Mediterranean tract into eastern Europe and perhaps to the Caspian-Ural region of Asia; indeed, it is not altogether improbable that straits or narrow seas may have connected with the apex of the Indian ocean. At least in the later Permian times the marine faunas of India and of Europe were notably similar, and in the early Mesozoic they became so nearly identical as to make a connection along this line extremely probable.

Effect of the supposed geographic changes on atmospheric circulation.—While none of these postulated changes involve great terrestrial movements, or depart widely from the rather definite indications of the phenomena concerned, it will be seen upon a study of the resulting distribution of land and water that they probably profoundly affected the circulation of the atmosphere. The limitation of the Atlantic at the north by the European-American connection rendered it essentially an equatorial and warm temperate ocean. Its present high-latitude connection, involving the transportation of vast quantities of ice and cold water into it from polar regions and the reciprocal loss of heat borne into the high latitudes by the Gulf Stream, was eliminated. The atmospheric function of the Atlantic was, therefore, radically changed. That great oblique factor to which was assigned so large a function in the localization of Pleistocene glaciation, was largely absent from the Permo-Carboniferous circulation. To the similar restriction attributed to the north Pacific a minor limitation of a like kind may be assigned. Instead, therefore, of a polar sea exchanging its thermal properties with an equatorial sea, as at present, there would be substituted a prevailing polar land, relieved probably only by the deep basin of the Arctic sea, whose limited extent and land-locked situation would render it little more significant in general climatology than the present Mediterranean.

On the other hand, very notable oblique features appear in the equatorial and southern regions. The postulated changes of the Pacific Ocean, by shutting off its connections with the Indian Ocean, probably brought into effective influence its long northwesterly and southeasterly trend, now neutralized by its

westward connections. In other words, the somewhat balanced distribution of the present Pacific was replaced by an effective obliquity which could scarcely have failed to powerfully influence the general circulation of the Paleozoic atmosphere. The northwest-southeasterly extension of the great Eurasian-Australian land paralleled this and intensified its effects. In other words, the Pacific Ocean and the parallel Eurasian-Australian continent constituted, in Paleozoic times, a couplet of oblique features that were chiefly effective in the equatorial zone and the southern hemisphere. They replaced the similar pair now formed by the north Atlantic and the eastern continent. It is inferred, therefore, that an obliquity of circulation of a pronounced order prevailed in Permo-Carboniferous times, by virtue of which the southern hemisphere was brought under the influence of meteorological agencies analogous to those that in Pleistocene times affected the northern hemisphere.

Some differences, however, are to be noted. The equatorial zone was then profoundly affected by the oblique features which lay directly athwart it. In addition to this there was the peculiar configuration of the Indian Ocean already set forth, namely, a broad, open mouth extended to the Antarctic polar regions, with a convergence to a narrow equatorial apex 20° or more north of the equator. The general course of the circulation in this may be assumed to have been much as it is today; that is, a movement in the polar latitudes, at first northerly and easterly, then curving about to the northward and northwestward as it approached the equatorial zone, and at length returning to the southwest along the African coast, thus forming a free circulation between the high latitudes and the low latitudes, with high latitude influences greatly preponderant. This circulation in Paleozoic times may be reasonably assumed to have been much more intense than at the present time, first, because there were then, by hypothesis, greater intensities of temperature, and second, because a larger percentage of the Antarctic waters were forced to flow into the apex of the Indian Ocean by the configuration of the land. This last statement would hold true even

if New Zealand were not connected with the Antarctic continent and South America, for the avenue of escape toward the Pacific would be circumscribed by the minimum elevations which the Gondwána phenomena seem to require. If the Antarctic-South-American connection were made, it would form a barrier to circumpolar circulation, and all the polar ice-drift from South America to New Zealand would doubtless be forced northeasterly into the Indian Ocean. This would certainly lend great intensity to the circulation of the polar currents through the Indian Ocean. The temperature of the latter would therefore be radically affected by the immense quantities of ice and cold water carried through it by this intensified circulation under the atmospheric conditions postulated. A like profound influence upon the overlying atmosphere must necessarily have followed. The narrow apex of the ocean under the tropics would probably have afforded little relief from the dominance of these currents.

If this cold area be contrasted with the heated state which should naturally prevail in the Pacific Ocean, because of its vast breadth under the equator, its limitations at the north and its somewhat narrow communication at the south (particularly if it be shut off from the Antarctic flow past New Zealand) should give rise to antithetical conditions of temperature and pressure sufficient to radically influence the general circulation of the southern hemisphere. It is conceived that this extraordinary couplet might even introduce a systematic exchange of atmospheres between the northern and the southern hemispheres, consisting essentially of a cold north-seeking current flowing across the Indian Ocean into the northern hemisphere, correlated with a warm return current flowing from the northern to the southern hemisphere across the tropical regions of the Pacific, but this conception is not regarded as a vital part of the hypothesis.

The configuration of the Atlantic is supposed to have caused it to play a subordinate part, the northern portion becoming an auxiliary of the Pacific and the southern portion more or less largely an auxiliary of the Indian Ocean. If we assume that the Gondwána extension connected New Zealand with the Antarctic

lands and South America, the ocean currents may be pictured as sweeping eastward from South America along the icy borders of the Antarctic continent into the great bay south of Australia, out of which they recurved and flowed northward across the equator to the Indian peninsula, which they freely bathed, and, returning along the supposed Gondwána connection, wrapped about South Africa and then flowed northward toward the equatorial regions, a portion then curving backwards and descending the coast of South America to complete the circuit. Such a circulation would throw perhaps two thirds of the antarctic influence into the Indian Ocean. On the other hand, seven eighths or more of the equatorial influence would probably be brought to bear upon the Atlantic and Pacific oceans. As a result these oceans, notwithstanding the impoverished condition of the atmosphere, received and retained a large percentage of the sun's heat.

Referring to the principles stated earlier in this discussion, it may be remembered that it was noted that a diathermous atmosphere permits a larger part of the sun's heat to reach the surface of the earth than a thermally opaque atmosphere, and that the portion which falls upon the ocean for the most part penetrates it until it is absorbed. A certain part, to be sure, is reflected, but in the zone of nearly vertical rays this is reduced to the minimum. As the result of the ocean's ability to absorb and retain heat, the diathermacy of the atmosphere is of less consequence in equatorial oceanic regions than in land tracts and hence the great equatorial oceans may have remained measurably warm throughout the glacial period.

It is conceived, therefore, that under these conditions, glaciation may have been produced in exceptionally low latitudes, and that its distribution was closely associated with the Indian Ocean. At the same time it is conceived that the lands immediately adjacent to the Atlantic and Pacific oceans, especially in low latitudes, were so far affected by the favorable thermal condition of those great bodies as to enjoy relatively mild temperatures, at least temperatures sufficiently genial to save them and the

adjacent lands from the exterminating effects that might naturally be associated with a glaciation in the tropics.

Relative to the more specific location of the Permo-Carboniferous glaciation, it may be noted that a tendency to form "lows" in India, Australia, and South Africa, not far from the ancient glaciated areas, is observable even under the present conditions. It is presumed that much more pronounced eddies were, in Permo-Carboniferous times, located on the borders of the cold belt formed by the intensified antarctic circulation and that these determined the areas of specific glaciation.

Conditions in the northern hemisphere.—In the arctic regions, a very low temperature may be confidently postulated under the supposed conditions, because of the extent of the land and the absence of oceanic circulation between the high north and the equatorial regions. A Siberian climate of an intensified order is therefore assumed to have prevailed over the high latitudes of the northern hemisphere. This may doubtless have given rise to limited accumulations of snow in favored localities, developing into glaciers, but on account of the general low precipitation and the dryness of the atmosphere, giving rise to large evaporation, this may not have become a pronounced fact. In so far as glacial deposits originated in the interior of the land they would be liable to destruction by surface denudation before submergence. The Permo-Triassic land period was long. Here and there, as already noted, there are phenomena which find their easiest explanation in glaciation and ice transportation. It is to be anticipated that, if this view be correct, further indications of severe temperature in northern latitudes will be developed in the course of future studies. It may be remarked that there is now nearly as much evidence of Permian glaciation in the northern hemisphere in regions away from mountains as there is of Pleistocene glaciation in the southern hemisphere in like situations.

As remarked at the outset of this part of the paper, a really satisfactory discussion of the Permo-Carboniferous glaciation is impossible in the present state of knowledge. I am by no means blind to the uncertain factors that inhere, at once, in the time

relations, in the geographic features, and in the meteorological inferences drawn from them. The most that could be hoped from an attempt to explain so extraordinary phenomena in so imperfect a condition of the data is to suggest the general direction in which, perchance, the truth may ultimately be found to lie.

T. C. CHAMBERLIN.

Editorial

The "Commissão Geographica e Geologica" of the State of São Paulo, Brazil, has just issued its first topographic sheet — a preliminary edition of the "folha de S. Paulo." This is a thirty minutes sheet on a scale of one to one hundred thousand with contours twenty-five meters apart covering the region between São Paulo and Santos, and including both of those cities. It crosses one of the most characteristic and interesting pieces of topography of all South America — the Serra do Mar. The bit of coast shown in the vicinity of Santos is also a characteristic one, while the high plateau of the interior is beautifully shown between the crest of the serra and the city of São Paulo.

Among other things brought out by this map is the evidence of a late depression of the coast. The bay of Santos and the estuaries thereabout are the remnants of a once much larger island-dotted bay that extended from Guaruja on the present coast to Cubatão at the foot of the Serra. The mud buried hills that protrude from the marshes about Santos are only the summits of mountains whose bases were carried beneath the ocean water by this depression.

The map is printed in three colors: the hydrography in blue, the topography in brown, the remainder in black. In appearance it is up to the highest standards of modern map making, and reflects great credit upon everyone responsible for its preparation and publication. That such work has been provided for by the State of S. Paulo, and that the people have had the patience to await the slow and tedious processes of triangulation, field work, office work, and all the other preliminaries of a good map, is the most healthful and encouraging evidence we have yet seen of the high intelligence and modern progress of

that part of South America. It is pleasant to note that this important work has been entrusted to our fellow countryman and colleague, Professor O. A. Derby, and that his chief topographer, Mr. Horace E. Williams, received his training in this country.

J. C. Branner.

A REFERENCE LIST OF SUMMARIES OF LITERATURE ON NORTH AMERICAN PRE-CAMBRIAN GEOLOGY, 1892 TO THE CLOSE OF 1898.[1]

In the Archean and Algonkian Correlation Paper, by C. R. Van Hise (Bulletin 86, U. S. Geol. Survey, 1892), North American pre-Cambrian literature was fully summarized from the time of the earliest publications to 1892. Since 1892, summaries of pre-Cambrian literature have been published from time to time in the Journal of Geology by C. R. Van Hise, and have lately been continued in the same periodical by C. K. Leith. The summaries thus far published are supposed to cover the field of pre-Cambrian geology for North America from 1892 to the close of 1898. To facilitate reference to the summaries and original articles there is given below a list of the articles summarized, arranged alphabetically according to authors' names, together with the volume and page of the Journal in which the summary appears. At the end there will be found a list of the principal regions of pre-Cambrian exposure, and under each region the names of the men whose articles on the pre-Cambrian of that area have been summarized.

The summaries here listed and those to follow for the years 1899 and 1900 will serve as a basis for a bulletin, to be issued under the joint authorship of C. R. Van Hise and C. K. Leith, supplementary to Bulletin 86, U. S. Geol. Survey. It is probable that there are a number of omissions and errors in the summaries listed, and it is hoped by sending out this bibliography that a number of them may be noted and brought to the attention of the

[1] The summaries have appeared in the Journal of Geology as follows:
Vol. I, 1893, pp. 304–314, 532–541.
Vol. II, 1894, pp. 109–118, 444–454.
Vol. III, 1895, pp. 227–236, 709–721.
Vol. IV, 1896, pp. 362–372, 744–756.
Vol. VI, 1898, pp. 527–541, 739–753, 840–854.
Vol. VII, 1899, pp. 190–205, 406–425, 702–708.

authors, who would be glad to know also of any errors or omissison in Bulletin 86 itself. Any correspondence with reference to them should be addressed to C. K. Leith, Madison, Wis.

In order that the purpose and scope of the summaries may be clear to every one, there is repeated below the prefatory note published by C. R. Van Hise with the first lot of summaries appearing in the JOURNAL.

The summary proper and the comments are kept wholly separate, in this way preventing the confusion which frequently comes from a mingling of the two. In the summaries the original language of the author is used as far as practicable, although a single sentence may be taken from several sentences of the original. Where it is disadvantageous to use the original language, other words are used. This often is necessary because the language which is adapted to complete exposition is often not the best adapted to résumé. No quotation marks are used; for the ideas contained, whether in the original language or not, are wholly the ideas of the author, and the whole is in fact quoted. It might be thought that better results would be reached by indicating through quotations what words are taken from the original, but this method would necessitate an unpleasant and constant alternation from quoted to non-quoted phrases. As a result of experience with the two methods, the editor feels certain that he is able more accurately and fully, in a brief space, to represent the ideas of the original author by the method proposed, than by following the usual method.

The summaries are confined to articles or parts of articles pertaining to pre-Cambrian stratigraphy. Purely economic or petrological articles are not summarized unless they concern pre-Cambrian stratigraphy, in which case the substance of the conclusions is given, rather than a full account of the observations and the manner of reaching them.

The abstracts have the defects of all summaries,—a certain amount of inaccuracy, because many modifying and qualifying facts cannot be given, and because undue emphasis is placed upon the conclusions.

In many cases no comments are made. This does not imply that the editor agrees with the statements of the summaries. To criticise, qualify, or refute the statements of the authors in all cases of disagreement, would often result in extending the space taken by the comments beyond that required for the summaries. However, when the

points at issue are of general interest or of fundamental importance, it is advisable to make comments and enter into discussions, even if the space taken by such comments be greater than that given to the summary of the original articles. In such comments neither commendation nor censure will be made, but the aim will be to point out the conclusions announced which fail of complete establishment and the generalizations which appear to go beyond what is warranted by the facts published. The purpose of indicating what appear to the editor as deficiencies of these kinds is neither to put himself dogmatically in opposition to the statements of the author reviewed, but to direct attention to the questions involved, and in cases of doubt to keep them open for further study in the field and laboratory.

ADAMS, F. D.

Norian oder Ober-Laurentian von Canada. (Neues Jahrb., B. B. VIII, 1893, pp. 419–498.) Summarized Journ. of Geol., vol. 2, p. 110.

On the typical Laurentian area of Canada. (Journ. of Geol., vol. 1, 1893, pp. 325–340.) Summarized Journ. of Geol., vol. 2, p. 111.

Preliminary report on the geology of a portion of central Ontario situated in the counties of Victoria, Peterborough, and Hastings, together with the results of an examination of certain ore deposits occurring in the region. (Ann. Rept. Geol. Surv. of Canada, for 1892–3, vol. 6, part J, pp. 15. 1895.) Summarized Journ. of Geol., vol. 3, p. 229.

A further contribution to our knowledge of the Laurentian (Art. VII). (Am. Journ. of Sci., 3d ser., vol. 50, 1895, pp. 58–69. With plates I and II.) Summarized Journ. of Geol., vol. 4, p. 364.

Laurentian area in the northwest corner of the Montreal sheet. Supplementary chapter to Ells' report on a portion of the Province of Quebec. Ann. Rept. Geol. Surv. of Canada, for 1894, vol. 7, part J, pp. 93–112. 1896.) Summarized Journ. of Geol., vol. 6, p. 850.

Report on the geology of a portion of the Laurentian area lying to the north of the island of Montreal. (Ann. Rept. Geol. Surv. of Canada, for 1895, vol. 8, part J, pp. 184. 1897. With geol. map.) Summarized Journ. of Geol., vol. 7, p. 411.

——and BARLOW, A. E.

On the origin and relations of the Grenville and Hastings series in the Canadian Laurentian. (Am. Journ. Sci., 4th ser., vol. 3, 1897, pp. 173–180.) Summarized Journ. of Geol., vol. 7, p. 413.

AGUILERA, JOSÉ G.

Sinopsis de Geologia Mexicana. (Bol. del Inst. Geol. de Mexico, Nums, 4, 5, and 6, part 2, 1897, pp. 189–250. With geol. map.) Summarized Journ. of Geol., vol. 7, p. 707.

BAILEY, L. W.

Preliminary report on geological investigations in southwestern Nova Scotia. (Ann. Rept. Geol. Surv. of Canada, for 1892–3, vol. 6, part Q, pp. 21. 1895. With geol. map.) Summarized Journ. of Geol., vol. 4, p. 362.

Report on the geology of southwest Nova Scotia. (Ann. Rept. Geol. Surv. of Canada, for 1896, vol. 9, part M, pp. 154. 1898. With geol. map.) Summarized Journ. of Geol., vol. 7, p. 423.

BARLOW, A. E.

Relations of the Laurentian and Huronian on the north side of Lake Huron. (Am. Journ. of Sci., 3d ser., vol. 44, 1892, pp. 236–239.) Summarized Journ. of Geol., vol. 1, p. 308.

Relations of the Laurentian and Huronian rocks north of Lake Huron. (Bull. Geol. Soc. Am., vol. 4, 1893, pp. 313–332). Summarized Journ. of Geol., vol. 2, p. 114.

——— and FERRIER, W. F.

On the relations and structure of certain granites and associated arkoses on Lake Temiscaming, Canada. (Geol. Mag., vol. 5, 1898, pp. 39–41.) Summarized Journ. of Geol., vol. 7, p. 419.

See Adams.

See Ells.

BASCOM, F.

The ancient volcanic rocks of South Mountain, Pennsylvania. (Bull. U. S. Geol. Surv., no. 136, 1896, pp. 124. With geol. map.) Summarized Journ. of Geol., vol. 6, p. 530.

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WRITERS CLASSIFIED BY REGIONS.

THE ORIGINAL LAURENTIAN AND HURONIAN AREAS (Eastern Ontario and Western Quebec).
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THE LAKE SUPERIOR REGION.
Bayley, Berkey, Blue, Boss, Clements, Coleman, Culver, Elftman, Finlay, Grant, Gresley, Hubbard, Lane, Lawson, Newett, Parks, Smith, W. H. C., Smyth, H. L., Spurr, Van Hise, Wadsworth, Winchell, N. H., Winchell, H. V., Winchell, A.

THE GREAT NORTHERN AREA OF CANADA.
Dawson, G. M., Dowling, Gibson, Low, McConnell, Tyrrell.

EASTERN CANADA AND NEWFOUNDLAND.
Bailey, Bonney, Dawson, G. M., Ells, Low, Matthew, Miller.

CANADA, GENERAL.
Dawson, G. M., Dawson, Sir Wm., Gibson.

THE NEW ENGLAND STATES.
Collie, Dale, Daly, Davis, Emerson, Hitchcock, Hovey, Sears, Whittle.

THE MIDDLE ATLANTIC STATES.
Bascom, Clark, Cushing, Darton, Grimsley, Hollick, Kemp, Keyes, Lesley, Marsters, Merrill, F. J. H., Merrill, G. P., Nason, Ries, Smyth, C. H., Westgate, White, Williams, G. H., Wolff.

THE SOUTHERN ATLANTIC STATES.
Clements, Darton, Hawes, Hayes, Keith, Kimball, King, Smith, E. A.

ISOLATED AREAS IN THE MISSISSIPPI VALLEY.
Beyer, Buell, Frazer, Hall, Haworth, Hill, Keyes, Nason, Norton, Osann, Sardeson, Todd, Weidman, Winslow.

THE CORDILLERAS.
Aguilera, Cross, Dawson, G. M., Eldridge, Emmons, Gilbert, Griswold, Hague, Iddings, Lakes, Lawson, Mills, Peale, Pirsson, Russell, Sapper, Walcott, Weed.

MEXICO AND CENTRAL AMERICA.
Aguilera, Sapper.

C. K. LEITH.

MADISON, WIS.

Reviews

The Upper Silurian fauna of the Rio Trombetas, State of Pará, Brazil. By John M. Clarke. *Archivos do Museu Nacional do Rio de Janeiro*, 1897–1899, Vol. X, 1–48. Rio de Janeiro, 1899.

Devonian mollusca of the State of Pará, Brazil. By John M. Clarke, *idem* 49–174.

These two papers are published in both English and Portuguese and are accompanied by eight beautifully drawn quarto plates, done by lithographers accustomed to work of this kind, illustrating all the species described.

The collections described are those made in 1876, in the Amazon valley, by the extinct "Commissão Geologica" or Imperial Geological Survey of Brazil. When the survey was suspended in 1877 the collections were turned over to the National Museum at Rio de Janeiro, and through the efforts of Professor O. A. Derby, previously a member of the survey and later director of the geological section of the National Museum, these unique collections were placed in the hands of Dr. John M. Clarke, one of our best American paleontologists. Dr. Clarke had already described and figured the trilobites of the Ereré and Maecurú sandstone, his paper appearing in Vol. IX of these same archives. The papers here mentioned make his second important contribution to our knowledge of the paleontology of the Amazon valley, and the most valuable since the publication of Dr. C. A. White's great work upon the Cretaceous fossils of Brazil.

At the end of the second paper he gives a list of the Devonian species of the Lower Amazon region, and finds the Ereré fauna to be "a miniature of the Hamilton" of New York (p. 158). The Curuá fauna he considers a member or modification of the Maecurú group. The rocks from which these fossils come are exceedingly rich, one locality, Ereré, furnishing forty-eight species, and, another, Maecurú, seventy-eight species.

In his summary concerning the Silurian fossils Dr. Clarke says that "the lower and upper Silurian elements of this little fauna are pretty equally commingled, and the inference is quite natural that in this

region the break in the record represented by the conventional plane of separation between the upper and lower divisions of the series is here obliterated. . . . . The little fauna is the oldest yet described from Brazil."

That last remark reminds me that some three years ago I published in this journal (Vol. IV, p. 975) a notice of an article by Dr. F. Katzer upon "The oldest fossiliferous beds of the Amazon region." In that article Dr. Katzer claims to have found graptolites in rocks said to have come from the Rio Maecurú region. Since the appearance of that note my attention has been directed to the fact that the article in question contained neither names, descriptions, nor figures of such graptolites, and that the origin of the fossils he mentioned was not really known—omissions that I should have observed without assistance.

It is a matter of painful interest to observe the great gaps of time between the collecting of the fossils by the Geological Commission, the date of Dr. Clarke's papers, and the date on the title page of this belated volume of excellent work.

We are accustomed in this country to hear more or less complaint about delay in the publication of government reports. But in this instance we may see if we will how much worse such matters might be. These collections were made in 1876, were placed in Dr. Clarke's hands in 18(?), the paper on the Silurian fossils was finished by him in 1891, that upon the Devonian in 1892, and the publication appears toward the end of 1899—twenty-three years after the field-work!

The inconvenience of this sort of thing is perhaps not as serious in Brazil where comparatively little is doing in science as it might be here or in Europe, but, like all other wrongs, sooner or later the country must pay for them. J. C. BRANNER.

The Cretaceous of the Black Hills as Indicated by the Fossil Plants. By LESTER F. WARD, with the Collaboration of Walter P. Jenney, William M. Fontaine, and F. H. Knowlton. Extract from the Nineteenth Annual Report of the U. S. Geol. Survey, Part II. Washington, D. C., 1899.

The results recorded in this extract are the outgrowth of a series of investigations beginning with the discovery of cycads in the Black Hills in 1893. From a study of these fossils and of their stratigraphical position, Professor Ward reached the conclusion that a part of the

so-called Dakota formation of the Black Hills belongs to the Lower Cretaceous series. This conclusion, together with the observations which led up to it, he published in the JOURNAL OF GEOLOGY in the following year. Since that time the work of investigation has been greatly extended through the efforts of Professor Ward and his co-laborers, with the result that his former conclusion is now fully substantiated.

New fossil localities were found, and many new species were collected. Of the cycads, one hundred and twenty-six trunks and fragments were examined. These were collected from two general although widely separated areas. The collection contains twenty-one species, all of which are new to science. Fossil forests are mentioned as occurring at the same horizon.

Professor Jenney makes a report on the Hay Creek region, in which he finds: a marine Jura characterized by an abundant invertebrate fauna; a later Jura resting unconformably upon the former, and characterized by saurian bones and fossil wood; above this the Lower Cretaceous, which he subdivides as follows: (1) the Hay Creek formation; (2) the Barrett shales; (3) the Oak Creek beds. The series is characterized by an abundant flora which contains no cycads.

The flora of the region is described by Professor Fontaine, who finds a number of species common to the Potomac formation, and a few common to the Kootenai. This suggests a closer relation with the eastern flora, but Mr. Ward thinks that this may not be the actual condition, as the Kootenai flora has not been as thoroughly investigated as the Potomac.

A few outcrops of the "Atlantasaurus beds" are reported as occurring on the eastern flank of the Black Hills. These consist of clays representing a thickness of about fifty feet and containing bones of saurians. The beds are thought to have been laid down in the depressions of the eroded surface of the marine Jura. W. N. LOGAN.

The Geology and Physical Geography of Jamaica: Study of a Type of Antillean Development. By ROBERT T. HILL. Bulletin of the Museum of Comparative Zoölogy at Harvard College, Vol. XXXIV, 1899. pp. 256, 41 plates.

The general scope of this volume, which is an important addition to the work which the author has heretofore done on Antillean geology,

is indicated by the title of the several parts of the volume. These are as follows: Part I, Geography and Physiography; Part II, The Geologic Structure and Sequence; Part III, Paleontology of the Jamaican Sequence; Part IV, Relations of the Jamaican Formations to those of Adjacent Regions; Part VI, Changes of Physiography in Tropical America bearing upon the History of the West Indian Islands; Part VII, Appendices (1) Additional Note on the Geology of Porto Rico and Santiago de Cuba, and (2) Some Cretaceous and Eocene Corals of Jamaica (by T. Wayland Vaughan).

Geography.— Geographically the island is described as follows: There is a central mountain axis in the eastern third of the island, the highest point of which is between 7000 and 8000 feet above sea level. About this mountain axis, with its chief extension to the west, is a plateau ranging from 1000 or 1200 feet, to 3000 feet. The plateau is really a gentle arch, and its greatest elevation is in the central part of the island. The plateau terminates abruptly by steep slopes known as the "back coast border." The margins of the back coast border are irregular, the result of valley excavation. The plateau is chiefly of limestone, and its interior topography is largely the result of solution and interior drainage. The plateau contains many remarkable basins developed in this way. Some of them have no outlets, while others have recently been tapped by valleys working in from the margins of the plateau. The margins of the plateau are extensively terraced. On the east side of Montego Bay there are at least six terraces, and while the number elsewhere is fewer, some of them are at levels considerably above those shown at Montego Bay, so that the total number is more than six. The terraces are much interrupted by erosion, the oldest being least distinct, and most discontinuous. The highest occurs at elevations of 1800 or 2000 feet, an altitude quite above the top of the back coast border in some parts of the island. The second highest terrace occurs at an elevation of about 1500 feet, the next at 1000 feet, and others at 650, 300, and 200 feet respectively. The upper terraces appear to have been carved out of the limestone during the period of emergence which followed the deposition of the limestone. Those below 700 feet appear to have been carved in a later period of elevation, following a period of submergence, after the higher terraces were made. The terraces "have all been cut out of the land by gradational processes (base leveling and marine erosion) and represent pausation stages in two long periods of elevation" (p. 33).

If the back coast border of the plateau were continued seaward, the borders of the island would lie much beyond the present shore line, and from this and other phenomena it is inferred that the former extension of the island was considerably greater than the present. There are terraces on the submerged slopes of the island similar to those above the water, which are in harmony with this view.

Bordering the plateau below the back coast border there is a coastal plain which is nearly continuous. In some places it is narrow, and in others it reaches far back into the island. The coastal plain is made up of three sorts of formations, elevated reefs, sea margin débris, and land alluvium. The coastal plain is more or less terraced by old wave-cut terraces, which have since been submerged and are now veneered with later deposits. The highest is about 150 feet above sea level. Elevated reefs occur at three levels, 60, 25, and 15 feet or less, respectively, above sea level.

The streams of the island belong to two types: (1) the autogenous type, with the peculiarities which go with changes of level; and (2) the interior streams which drain into limestone sinks. In addition to these two types, there is a combination type which results from the capture of the interior drainage by streams which flow seaward.

A topographic map with 250-foot contours and a geologic map accompany the volume, and help to make the geography and geology clear.

Geology.—The central mountain axis of the island is made up of rocks known as the Blue Mountain series. This series is made up chiefly of "loose or slightly indurated beds of gravel, clay, bowlders, and tuffs, with exceptional beds or bosses of hard indurated limestones and yellow clay. The rocks are usually of dark color . . . . in strong contrast to the glaringly light colors which characterize the succeeding formations of the oceanic and coastal series. The material, with the exception of occasional limestone beds and a few outcrops of clay marls, can be traced to igneous rocks; it was first volcanic ejecta and subsequently and successively underwent various degrees of attrition and sedimentation" . . . . (p. 41).

This Blue Mountain series constitutes the surface formation of all parts of the island which rise above 3000 feet. From exposures at lower levels where erosion has removed the overlying strata, it is known that the same series has extensive development beneath the younger formations, and from the known exposures the series is believed to

underlie most of the island. The beds of the Blue Mountain series are much deformed. Since a continuous exposure of the total series is nowhere found, exact measures of thickness have not been obtained, but it is stated that the thickness probably exceeds 5000 feet.

The Blue Mountain series is made up of Upper Cretaceous and Lower Eocene beds. There seems at this point to be a little confusion in the classification, since the Richmond formation, which appears to be the upper part of the Blue Mountain series, is classed as Eocene at some points (geological map), but as Upper Cretaceous at others (p. 143). The Blue Mountain series is exposed in the central and western parts of the island at levels which are below the mountains of the east. In these localities, erosion has removed the overlying beds.

The Blue Mountain series is overlaid by the Cambridge formation, a formation not extensively exposed. Where it appears, it skirts the older series. It is made up of clays, marls, and yellow limestones, and occupies a transitional position between the older series, the material of which was derived from land formations, and the next succeeding formation, the material of which is limestone, and therefore of oceanic origin. The Cambridge formation is classified as late Eocene.

The Cambridge formation is followed in stratigraphic order by an extensive formation of White Limestone, the principal formation of the plateau. It has by far the widest surface development of any formation on the island. It covers the whole of the island between the top of the plateau (3000 feet) and the coastal plain, and underlies some portions of the latter. In the western part of the island it completely covers (or once did) the Blue Mountain series. The beds of limestone are often considerably disturbed. The formation is assigned a deep water origin, since it contains neither reef corals nor littoral shells. Its fossils are mainly microscopic, and it is referred to the earlier part of the Oligocene period.

The formations of the island younger than the White Limestone belong to the coastal series, and were made after great changes had affected the island. These coastal formations are made up of four sorts of rock: (1) marine beds, (2) alluvium, (3) elevated coral reefs, and (4) littoral deposits.

The oldest of these formations is known as the Bowden formation, the age of which seems to be in some doubt. It is regarded as either

late Oligocene or Miocene. The formation was deposited after a subsidence which followed the uplift and extensive erosion of the White Limestone. The break between it and the White Limestone is, therefore, a great one, and on general grounds it would seem more in accord with modern classification to make the break between these two formations the division between the Oligocene and Miocene than to place it in the Oligocene. The Bowden formation has a thickness of something like 250 feet. Its outcrop consists of a fringe around the older plateau region, and it is, in turn, bordered by still later and lower-lying formations. The Bowden formation is made up of various sorts of sedimentary rock.

The next succeeding formations are classed as Pliocene. They are composed of marl and limestone of marine origin (Manchioneal), and of slight thickness, and of gravels from the uplands. The gravels are in part estuarine, in part subaërial, and in part littoral. The Pliocene formations have relatively slight surface development, though considerable areas in the vicinity of Kingston are covered by them.

Among the Pleistocene formations are beds of reef rock, ten to forty feet in thickness. They range in elevation from sea level up to seventy feet. They lie on eroded land surfaces, and their relations are significant of the movements to which the land had been subject before their formation. Other Pleistocene formations consist of chalky marls at low levels near the coast. Here belongs especially the Falmouth formation which rarely occurs higher than fifteen feet above the sea. The Falmouth formation is nothing more than a series of unconsolidated sea muds, probably synchronous with the younger elevated coral reefs. Among the latest formations are the alluvial deposits in valleys about the shores. In Montego Bay there are low islands which owe their origin primarily to mangroves.

There are some igneous rocks on the island. The oldest are the bowlders of andesite in the Blue Mountain series. The source of this igneous matter is unknown. There are mid-Tertiary igneous rocks in the form of dikes, laccoliths, etc., composed of hornblende-diorite, and granite-porphyry. These intrusive rocks affect the Blue Mountain series, and extend upward into the White Limestone above, but are found only in the eastern third of the island. In a single locality on the north coast near the east end of the island there is eruptive amygdaloidal basalt. There is everywhere more or less metamorphism in association with the igneous rocks.

The topography and stratigraphy of the island suggest the following sequence of events :

1. The first event in the history of the island so far as now known is the igneous activity which furnished the material for the Blue Mountain series. This was probably in Cretaceous time. The oldest formation of the island is composed of the débris of this activity. The amount of the débris was great, indicating that the volcanic activity was extensive.

2. The degradation of the volcanic débris and the re-deposition of the material in the form of sedimentary formations (the Blue Mountain series) was the second great event in the history of the island. The formation is such as to show (*a*) that there was rapid erosion and deposition; (*b*) that the land from which the sediments came was high; and (*c*) that the deposition was accomplished in shallow water.

3. The next event was the elevation, and, perhaps, the folding, of the beds of the Blue Mountain series. The folding probably followed the deposition of the Richmond (Eocene) formation; that is, was mid-Eocene. On this point, however, the author is not altogether satisfied, and indicates that the folding may possibly have occurred later.

4. The next event was the sinking of the island, probably late in the Eocene period, followed by the deposition on the submerged surface of the great White Limestone formation. The subsidence is estimated to have been at least 1200 fathoms. This great subsidence submerged all but the higher parts of the Blue Mountain series, leaving at most only the parts which are now more than 3000 feet high out of water. The subsidence may have been even greater, submerging the whole island. The evidence of this great subsidence is found in the Montpelier chalk (the lower part of the White Limestone), the composition of which indicates, according to Mr. Hill, a depth of 1200 to 2300 fathoms. Further evidence of the great subsidence is found in the stratigraphically equivalent radiolarian earths in eastern Cuba—earths which call for depths of 3000 to 4000 fathoms. Mr. Hill thinks it would not be unfair to assume 10,000 feet as the mean subsidence of Jamaica (p. 165). The argument of Mr. Hill for so great a sinking does not seem altogether conclusive. If the whole of the island were submerged, and this would not seem to call for so great a subsidence (though still a great one) there is no apparent reason why formations due to pelagic life should not be made in shallow water, even though too deep for corals and other shore-life. A few hundred feet of water

would destroy these shallow water forms, and since there would be no source for terrigenous material, the shells of pelagic life should have been the chief source of sediment. The problem is the same as that presented by the Niobrara chalk of the United States. It shows absence of terrigenous sediment rather than great depth of water.

5. The next event in the history of Jamaica was the re-elevation of the island in the Oligocene period. The amount of elevation is estimated at 13,000 feet. If the preceding subsidence were less than stated above, the call for so great a rise would disappear. After this re-elevation, the island is believed to have had a much larger area than now. The uplift was accompanied by a gentle folding of the rock, the folding having an east-west axis, and therefore making an angle with the axes of the older mountains, the trend of which is northwest and southeast. With the general arching of this time there were many minor folds. It is believed to have been in connection with this elevation that the igneous intrusions of mid-Tertiary time were effected, and the higher terraces on the margins of the plateau developed.

6. The next event was another subsidence, contracting the island to the back coast border. The depression is placed at about 3000 feet. It was at this time (as well as during the preceding interval of emergence) that the back coast border of the plateau was developed. During this minor submergence the Bowden formation (Miocene), reaching up to levels of 300 feet, was deposited.

7. This subsidence was followed by an elevation. The Blue Mountain ridges and the plateau were elevated some 500 feet. The borders must have been elevated much more, for the southern coast is believed to have been extended out to about the present 500-fathom line. This movement of elevation was less orogenic in its character than any of the preceding, and was followed by a period of erosion. During the pre-Bowden epoch of erosion the streams did not get their heads far back into the plateau, but developed great amphitheaters near the edge of the back coast border, while great basins were being developed in the interior. During the post-Bowden interval of erosion, the coast streams worked back, and drained out many of these interior basins. It was during this elevation that the middle terraces, of the back coast border — those at elevations of 200 to 700 feet — were developed.

8. The next event was probably a late Pliocene subsidence of not more than 700 feet. This submerged the border of the island to the

base of the back coast border, covering the present low borders with littoral and estuarine formations.

9. The next and last event was an epeirogenic movement of upward phase, amounting to about 800 feet, which raised the submerged borders into the present coastal plain. This upward movement may have been interrupted by a minor subsidence, in early Pleistocene times.

There were, therefore, according to this interpretation four distinct periods of subsidence after the deposition of the Blue Mountian series. (*a*) The subsidence which preceded the deposition of the Montpelier (Oligocene) formation; (*b*) the subsidence which preceded the deposition of the Bowden (Miocene) formation; (*c*) the subsidence which prepared the way for the Manchioneal (Pliocene) formation, and (*d*) the subsidence which resulted in the deposition of the Pleistocene marine formations within the present land area. These four subsidences alternated with corresponding elevations: the first in the mid-Oligocene period, elevating the White Limestone; the second in the late Miocene, lifting the Bowden formation; the third in the early Pleistocene, bringing up the Pliocene formation; and the latest, exposing the marine Pleistocene. This series of uplifts and depressions constituted a diminishing series, being in this respect in consonance with other Antillean and with mid-American phenomena. The post-Richmond (early Eocene), the post-Moneague (mid-Oligocene, White Limestone), and post-Bowden (Miocene) uplifts were orogenic, diminishing, however, in their orogenicity.

In that part of the volume which deals with the relations of the Jamaican formations to those of adjacent regions, the author announces the general conclusion that the Jamaican sequence is very like that of the other islands of the Great Antilles.

In his summary of the history of the Antillean region the following generalizations are given:

1. The geology and configuration present no evidence whatsoever whereby past land connections can be established between these islands and the North and South American lands in Post-Jurassic time, especially in the Tertiary, Pleistocene, or recent epochs.

2. The configuration and condition of these islands in pre-Jurassic time cannot even be surmised.

3. There are some hypothetical and biologic reasons for believing that the outer rim of the American Mediterranean constituted a partial or complete bridge between the continents in Jurassic time, and that the Panama bridge did not then exist.

4. The first definite evidence of Antillean lands is found in the eruptive rocks of late Cretaceous time, when it is probable that there were marine volcanoes.

5. The land débris constituting the Eocene strata throughout the islands testifies the pre-existence of extensive Cretaceous land areas.

6. There was a profound regional subsidence in late Eocene and early Oligocene time, which submerged all but the highest tips of the Antilles, and which extended to the margins of the surrounding continents.

7. In late Oligocene or Miocene time there was a tremendous oroganic movement which resulted in uplift, whereby many of the islands were connected with each other, and possibly an insular southern portion of Florida, but not establishing land connection with the North and South American continents.

8. In Miocene or early Pliocene time the islands were severed by submergence into their present outlines and membership, which they have since retained with only secondary modification.

9. In Pliocene and Pleistocene time there have been intermittent periods of elevation without serious deformation, but not sufficient to establish land connections or to restore the islands to the heights and areas of mid-Tertiary time. The Pleistocene movements, while epeirogenic, were sufficiently differential to show that they were not uniform in all parts of the area, showing great differences in amplitude within the West Indian area, and were not harmonious with those of the North American coastal plain.

10. The irregularities of the submerged configuration of the West Indian region are orogenic, and not due to submerged continental drainage systems.

11. The elevated coral reefs of the West Indies were formed on rising lands.

In appendices Mr. Hill gives an additional note on the Geology of Porto Rico and Santiago de Cuba, and Mr. T. Wayland Vaughan describes some Cretaceous and Eocene corals from Jamaica. The note on the geology of Porto Rico and Santiago de Cuba, based on a recent geological reconnoissance, is as follows:

1. An older plexus of water-sorted hornblendic volcanic material—tuffs and conglomerates with interbedded Cretaceous Rudistean limestone similar to that of Jamaica, composing the central mountains.

2. An Eocene system of impure lignitic sands and clays like the Richmond beds, occurring on the western side of the island near San Sebastian.

3. Fossiliferous marl beds overlapping the above, which at this writing have not been determined.

4. Miocene coral limestone, unlike anything hitherto recorded from the Great Antilles, but of the type occurring in Antigua. These constitute the hilly country north and northwest of Lares.

5. White limestones of probable Pliocene age, composing the hills of the south coast.

6. Elevated reefs, but feebly represented.

7. Alluvial plains of Pleistocene age. The terrace phenomena are less developed upon this island than in any of the other Great Antilles, although the Pleistocene base leveling is well developed in stream valley phenomena. Dikes of syenitic-like porphyry, probably diorites, were also noted cutting the older hornblendic rocks.

Evidence was obtained indicating that the great mountain movement culminated before the Miocene, and that there has been at least one thousand feet of vertical uplift since that epoch.

The recent work in Cuba consists of a section across the Sierra Maestra from the coast to the Rio Cauto. In making the section, Mr. Hill was convinced "that the crystalline rocks of that region are Cretaceous and post-Eocene Tertiary, and not Paleozoic, as asserted by Frazer. . . ."

R. D. S.

Die Stillstandslagen des letzten Inlandeises und die hydrographische Entwickelung des pommerschen Küstengebietes. By Dr. K. Keilhack. Separatabdruck aus dem Jahrbuch der königl. preuss. geologischen Landesanstalt für 1898. Berlin. Pp. 90–152, 14 plates.

The immediate object of this paper is to set forth the relations between the edge of the ice and the drainage of north Germany during the last glacial epoch. The general slope of south Germany is northward, and the general slope of the ice which lay over north Germany was southward. Along the meeting of these opposing slopes, water courses were developed while the ice was in existence. Locally these marginal water courses were lakes, but often there was a river current along them. Many of the peculiarities of topography and drainage date from the time of ice occupancy.

Incidentally, several points of general interest are developed. Dr. Keilhack recognizes three distinct glacial epochs. During the last he recognizes five more or less distinct stages of the ice, one standing for the maximum advance of this epoch, and the others recessional stages. Each of these stages had its marginal water course.

During its maximum stage the limit of the ice in this epoch was just north of the Malapane and Oder rivers, as far west as the northward

bend of the latter, southeast of Glogau. From this point west the edge of the ice was south of the Oder, having a general west-northwest course to Magdeburg. West of Magdeburg the position of the edge of the ice has not been determined. It was perhaps along the Aller River, and perhaps farther north along the divide between this river and the Elbe. During this stage of the ice marginal drainage was westward along the valley of the Malapane to the junction of that stream with the Oder at Oppeln, thence down the Oder to Breslau and beyond. Here the drainage left the present course of the Oder (which beyond this point was buried by the ice) and flowed west-northwest to the valley of the schwarze Elster, thence along that valley to the Elbe, and down the Elbe to its junction with the Saale.

The halting places of the ice during its retreat are recognized by three principal criteria. First, the *endmoräne*, which are bowlder walls (as that term is used by the Germans); second, the great ridge-belts of markedly undulatory topography regarded as terminal moraines in the United States; and third, the sand and gravel plains outside the ridges just referred to. All these criteria are found in connection with the edge of the ice at its various stages, but in better development in some cases than in others.

The edge of the ice during the first recognized halt in its retreat lay a few miles farther north, running in the same general direction. Roughly, it extended from Pleschen to Potsdam, and thence to a point near Lauenburg just north of the Elbe. West of Lauenburg the border has not been traced. The margin of the ice during this halt was more or less lobate. The marginal drainage was along the Bartsch-Baruth Valley to the Elbe north of Magdeburg. Farther west the course of the drainage is uncertain.

The second halt of the ice, marking the third position of a more or less stationary edge, lies still farther north, along the divide between the Warthe and the Netze from longitude 36° E. to Frankfurt on the Oder. Here the edge of the ice crossed the present course of the Oder, and extended westward and northwestward to Schwerin and beyond. During this stage the marginal drainage was westward along the course of the Warthe to the longitude of Posen, thence westward to the Oder and down the latter nearly to Frankfurt, thence westward by way of the Spree to Berlin, and thence west-northwest to the Elbe, and thence to the North Sea.

The third halt in the ice front shows that the recession was very unequal in different regions. In the eastern part of Germany the edge of the ice at this stage was far north of its position during the preceding stage, while in west Germany the differences in position were slight. Generally speaking, the border of the ice between the Weichsel and the Oder, lay along the divide between the Netze on the south, and the drainage which flows directly to the Baltic on the north. It crossed the Oder near Oderberg; thence it ran in a general northwest direction to Lübeck. From Lübeck it extended north-northwest through Jutland. During this halt the edge of the ice had two or possibly three great lobes. The greatest of these lay between Danzig on the east and Lübeck on the west. East of Danzig there was another lobe extending well southward, the eastern limit of which is not mapped. West of Lübeck the Jutland ice may be regarded as constituting a third lobe. Beside these great lobes, there were many minor crenations of the edge. This stationary position of the ice is the best known of all, partly because it has been more studied, and partly because it is far more distinct. All the criteria of the stationary edge find here their best development. The morainic (as that term is used in America) belt of this stage is the Baltic *Höhenrücken*. It is this belt which the reviewer traced out in a rough way in 1887, and characterized as the great terminal moraine of north Germany.[1] Dr. Keilhack says that this moraine is bordered throughout 650 of the 700 kilometers of its length in Germany by sand plains. The morainic topography of this belt is much more strongly developed than that of the other halting places, as also the *Endmoräne*. To Dr. Keilhack's conclusion that the ice along the fourteenth part of this 700 kilometers where sand plants are absent, disappeared chiefly by evaporation instead of by melting, we can hardly subscribe.

During this stage of the ice the marginal drainage was along the Thorn-Eberswalde Valley which connects with the Elbe southeast of Wittenberge. Along this course the water was partly fluviatile and partly lacustrine.

The fourth and last chief halting place recognized is near the Baltic. In receding to this position from the last the ice retreated most over the lowest ground, and least over the highest. A new marginal drainage line was formed not far from the coast, and roughly

[1] Terminal Moraines in North Germany, Am. Jour. Sci., Vol. XXXV, Series 3, pp. 401.

parallel to it from Danzig to Stettin, and thence *via* the Trebel to the Baltic near Ribnitz. Some parts of this marginal water course were fluviatile and some lacustrine, the largest lake being about Stettin. These lakes are described in detail. For the largest three distinct levels are made out, the highest of which is 25 meters above sea level. These stages are connected with the retreat of the ice, and the opening of new outlets. The development of the present Baltic drainage is described in great detail. Many of the north-south valley now draining to the Baltic are thought to have been originally subglacial valleys draining south to the marginal valley last mentioned before the ice melted away. The drainage through them was then reversed.

Between the fourth halting place of the ice and the Baltic Sea Keilhack makes out and maps eleven substages in the recession of the ice, each changing in some recognizable way, the drainage of the preceding stage. These subordinate stages, like the larger ones, show that the ice did not retreat at the same rate all along its front. So detailed a piece of work concerning drainage along the margin of the ice has not before been published.

One of the interesting facts brought out in this paper is the similarity of the phenomena of the last glacial epoch in Germany with those of the corresponding epoch in the United States. In the Wisconsin epoch the edge of the ice made several halts in its recession from its position of maximum advance. In each of these positions morainic belts were developed, and as in Germany the strongest of these belts was not at the position of maximum advance, but in a more northerly position. As in Germany, each morainic belt is bordered by sand plains. As in Germany, the recession of the edge was unequal, and here as there, the lobations of one stage did not correspond with those of another. The analogies might be carried much further, but not to the drainage from the ice, since similar topographic relations did not exist in the United States.

R. D. S.

Shore Line Topography. By F. P. GULLIVER. Proc. Am. Acad. of Arts and Sciences, Jan. 1899. pp. 151–258.

In this essay Mr. Gulliver presents the mature results of a very serious piece of work. The topography of shore lines is considered under *initial* forms and *sequential* forms. Under initial forms are

included those which shore action has not modified since the region concerned was uplifted or depressed (relative to the surface of the sea). Under sequential forms are included those features which are developed subsequent to the diastrophic change, by the forces at work along the shore. The larger part of the essay is naturally devoted to sequential forms.

The reading of this essay makes several things evident. In the first place, Mr. Gulliver has exhausted the literature on the subject with which he deals; and, in the second place, he has made diligent use of maps. In the use of this material he has gathered a large body of facts which he has attempted to interpret and classify. Not only this, but he has attempted to interpret and classify them *in terms of development*, so as to put the topography of shore lines on an equal footing with the topography of land surfaces, as an index of geographic evolution. So far as we are aware, this is the first time this task has been essayed, and the author is to be congratulated on the successful outcome of his study. Geography and geology are the gainers, and the future student of coast lines will hardly fail to consult this essay.

In the author's own words, the thesis of the essay is the following: "The forms of any coastal belt may be grouped in the appropriate stages of a cycle. These forms will be consistently related to the associated land area on the one hand, and to the sea bottom on the other. When considered together, the forms of a coastal belt indicate the relative time since the last considerable uplift or depression, as well as the ratio existing between the several activities, in their dynamic effect upon the forms of the coast and the shore." The whole essay is the expansion of this idea.

In consonance with this mode of treatment of the subject, the author has made use of many of the life terms, such as infancy, youth, adolescence, maturity, etc., which are now in use in connection with the history of rivers. Some of these terms have a new meaning when applied to coast lines, and their adoption will be at the cost of some mental effort. At the outset it will be necessary to stop to think what the terms mean in connection with coast lines, as distinct from what they mean when applied to land surfaces in general. This, however, is no serious objection to their use. On the first reading of the essay, it must be confessed that the use of biological terms sometimes seems a little forced. Such objections as may be entered to their use will be

charged to old-fogyism by those who like to see the old terms used in the new way, and to conservatism by others. The reviewer is prepared to go a good ways in the application of biological terms to geographic evolution, where the terms fit, but when a large and quickly built delta is called a "precocious infant" (p. 224), it seems to be going a trifle far. Such criticism is, however, on the surface of things; it touches nothing fundamental. Some new terms are introduced to designate forms which have been nameless, and some of them are so good and so much needed that they should be adopted at once. An example is "wave-base" (p. 176) to denote the plane to which waves may degrade the bottom in shallow water. It is the correlative of base level. Some other terms, however, do not at first seem so necessary or so happily chosen. To this class belongs "winged beheadland" to denote a sea cliff with a spit on either side (p. 213).

There are not a few minor points in the essay which might be criticised, but it seems almost ungracious to mention them in the presence of so many larger matters which deserve hearty commendation. Glacial erosion seems not to have due recognition among the agencies which shape shore lines. It is true that the author expressly disclaims his intention of discussing this point, and it is true that glacial modification of coasts are accidental, in the sense of not being a part of the normal cycle which is the theme under discussion, but it might have been well to recognize more fully the effects of glaciation in connection with some of the coasts referred to, even though the subject of glacial modification of coast lines is not discussed. The writers on Lake Agassiz are gently criticised for describing the shore lines of that lake as if they "were formed once for all and would forever remain as constructed" (p. 187), but the truth is, these shore lines are still sensibly as constructed, and no one has essayed to write up the history of the changes which these shores will yet undergo. It will be readily seen that when such minor points are the things which suggest themselves for criticism the essay as a whole is strong.

Not only is the essay a serious piece of work, as suggested at the outset, but, by means of the numerous references, both cartographic and textual, the author has placed the material on which he based his conclusions at the command of future students. From this material students may draw their own conclusions, and, judging from the tone of the essay, no one would be more ready to entertain alternative conclusions than Mr. Gulliver himself. R. D. S.

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